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WAsP - Wind Atlas analysis and Application Program. User's Guide. Release 1.0

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WA^{S}P

Wind Atlas
Analysis
and
Application
Programme

User's Guide

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Users Guide

Distribution

The WA^{S}P programme and ~~reference manual~~ are distributed solely by:

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Denmark

All correspondence regarding WA^{S}P should be directed to this company.

[1]Identical to the Order Form/Contract signed by the customer.

Contents

List of Figures

List of Tables

1 Introduction

WA$^{\mathrm{s}}$P—the Wind Atlas Analysis and Application Program—is a PC programme for the horizontal and vertical extrapolation of wind data. It takes into account the effect of different roughness conditions, sheltering effects due to nearby buildings and other obstacles, and modification of the wind imposed by hills and complex terrain. Thus, it provides the user with means of correcting the basic meteorological data, as well as offering tools for detailed siting of wind turbines.

WA$^{\mathrm{s}}$P can be considered as a further development along the lines laid forward in several publications of our group. The Danish Windatlas (Petersen *et al.*, 1981) presented basic surface wind statistics together with detailed procedures for estimating the wind speed distribution at any particular site and height. Later, the report "Extrapolation of mean wind statistics with special regard to wind energy applications", prepared for WMO by Jensen *et al.* (1984), discussed the micro-meteorological and statistical techniques in relation to wind energy estimation — with application to all parts of the world.

During the last five years our group has acted as main responsible for the European Windatlas Project (Petersen and Troen, 1986), a work which is now near completion. In the same period we have carried through a number of projects involving practical wind resource estimation and siting work in many parts of the world. Altogether, this has prompted us to develop and extend the calculation procedures of the Danish Windatlas. The work has involved:

- Adaption of models available in the literature, e.g. a shelter model based on the paper by Perera (1981).
- Development of new models, e.g. a high resolution complex terrain model (Troen, 1987) and a double kink change-of-roughness model.
- Testing of models using data from field experiments in which our group has participated or that we have performed ourselves. Examples of such experiments are the IEA-sponsored Askervein Hill Experiment 1983, to study the mean flow and turbulence over hills (Taylor and Teunissen, 1983), and the JYLEX Experiment 1982–85 to study the change of the mean flow profile downstream of a roughness-change on the scale of several kilometers.

Most of the different models developed were initially intended for our own scientific and practical consulting work only. However, about a year ago, we realized that we had at hand, or could fairly easy develop, an essentially complete "package" of sub-models for horizontal and vertical extrapolation of wind data. We found that such a package could be of interest to many people dealing with wind energy and related fields, provided that the programme could be designed in such a way that it did not require specialized knowledge in meteorology, climatology or flow modelling. This has now been accomplished with the WAsP programme, providing state-of-the-art methods for the professional as well as the non-specialist user.

1.1 Basic elements of WAsP

Although WAsP is very much an integrated programme, at least five distinct sub-models can be identified. These are:

1. **The roughness change model.** Downstream of a change in surface roughness an "internal boundary layer" develops, in which the wind profile slowly adjusts to the new surface conditions — see Jensen *et al.* (1984) for a detailed discussion. WAsP contains a sub-programme to model this, taking into account up to ten consecutive changes of surface roughness in each sector analysed.

2. **The shelter model.** The submodel for shelter behind single buildings, shelterbelts etc. is based on the work by Perera (1981) on shelter behind two-dimensional fences. The WAsP model for shelter behind three-dimensional obstacles also takes into account the reduction of shelter due to the lateral mixing at the edges and the possible interference of other nearby obstacles. Up to 50 obstacles can be handled at the same time.

3. **The orographic model.** WAsP includes a recently developed high resolution flow model, the socalled "BZ" model, for neutral flow in complex terrain (Troen, 1987). The BZ model is similar to the models presented by Taylor *et al.* (1983). It is a spectral model based on the work by Jackson and Hunt (1975). The model employs a "zooming" polar grid with resolution concentrated in one point. The input to the model is height contour lines (coordinate locations tracing lines of equal height) which can be obtained directly from most standard topographic maps. The scale of the grid is adjusted depending on the size of the domain described in the contour lines. With an outer radius of 50 km, the resolution at the center is 10 m.

4. **The windatlas analysis model.** This model is similar to the model used in the European Windatlas Project (Petersen and Troen, 1986). It performs correction of observed wind statistics by employing the models mentioned above. The result is an "atlas" of wind climate in the form of Weibull parameter tables corresponding to standard azimuth sectors, heights and surface roughness conditions. Both surface wind data and upper-air data can be used as input.

5. **The windatlas application model.** This model performs the inverse calculation as that of the analysis model. It employs the models described above to give an estimate of the wind climate at the site in question.

In addition to the models outlined above, WA^{s}P also contains a number of utilities. These are described in the subsequent chapters and summarized in appendix A.

1.2 The purpose of WA^{s}P

WA^{s}P was developed for the purpose of wind climate estimation, with special regard to wind energy applications. WA^{s}P should be thought of as a *tool* for both professional meteorologists and for non-specialists dealing with wind energy. It may also be used in other fields where horizontal and vertical extrapolation of wind data are employed.

WA^{s}P has been developed to a stage where it is simple to use, even without much knowledge of the underlying principles involved. It is a very powerful tool with which you may perform a complete and detailed siting exercise in a matter of minutes. This flexibility and ease of use has been obtained without compromising the accuracy and completeness of the meteorological models employed — WA^{s}P is not a reduced version of a main-frame computer code. It is, to the best of our knowledge, unequalled for the purpose of wind climate estimation in connection with wind energy. The general purpose of WA^{s}P has been implemented in the following four calculation blocks:

1. **Analysis of raw data.** This option enables an analysis of any time-series of wind measurements, compiling the raw data into histogrammes. These are the meteorological data input to WA^{s}P. The raw data are also analysed in terms of Weibull parameters.

2. **Generation of windatlas data.** Histogrammes of wind speed can be converted into a windatlas data set. The histogrammes may derive from the data analysis or may be entered directly from standard climatological tables. In a windatlas data set the wind observations have been "cleaned" with respect to site specific conditions and reduced to standard conditions.

3. **Wind climate estimation.** Using a windatlas data set calculated by WA^{s}P, or one obtained from another source, the programme can estimate the wind climate at any particular point by performing the inverse calculation as is used to generate a windatlas. The wind climate is estimated in terms of Weibull parameters and the sectorwise distribution of the wind. The Danish Windatlas is supplied together with WA^{s}P.

4. **Estimation of wind power potential.** The total energy content of the mean wind is calculated by WA^{s}P. Furthermore, an estimate of the actual, yearly mean power production of a wind turbine can be obtained by providing WA^{s}P with the power curve of the turbine in question.

2 Getting started

WAsP is distributed on two floppy diskettes, a Programme Diskette and a Data Diskette. The WAsP programme is protected with the SUPERLoK[2] software protection system. It allows you to make backup copies of the diskette, both onto floppy and hard disks, while preventing unauthorized duplication of your software. Unlike other packages which limit the number of protected packages to 1 per diskette, SUPERLoK allows you to have many different protected programmes per diskette or hard disk. In addition, SUPERLoK is invisible. Once you have installed the programme on your backup diskette or hard disk, you never know that SUPERLoK is there. WAsP will operate just like any programme without protection, except that SUPERLoK prevents unauthorized duplication of WAsP.

The following sections contain procedures for installing and uninstalling WAsP. The installation procedures are required so that you can run WAsP from one of your disks, either a floppy or a hard disk. The UNinstall procedures allow you to remove WAsP from your floppy or hard disk and move it to a fresh diskette or another hard disk. This is necessary since you are limited in the number of copies that the copy protection allows you to have. Even though WAsP is executable from the distribution disk, you are advised to perform the installation procedure so that you will always have a backup copy available.

2.1 Installing WAsP on your computer

Installation is a simple process performed through a series of prompts. The following procedure guides you through the process of installing to a floppy diskette. Where there is a difference between a floppy and a hard disk installation, the hard disk information is also given.

In the following description, the symbol <*cr*> represents pressing the RETURN key. Information you are to enter is printed in **bold**. Mandatory spaces are shown with the symbol ␣. Where your input may be different than the input shown (such as disk drive assignments) the information is underlined. Note that if you are performing a hard disk installation, WAsP will be executable from the current subdirectory. When you install to a floppy diskette WAsP must be located in the root directory.

Installation steps are as follows:

1. Insert the WAsP Programme Disk into the A drive.

[2]SUPERLoK is a trademark of Softguard Systems, Inc.

2. Make the A drive the default drive. This is done typing:

   A:<*cr*>

3. Start the installation programme by typing:

   A>**INSTALL**<*cr*>

4. The programme will now prompt you for the type of installation you want to perform as shown below:

   ```
   WAsP Install/UNinstall Procedure
   Enter letter for media to be installed to or UNinstalled from
   Use H for hard disk, or F for floppy disk=   F<cr>
   ```

   Your response can be either **F** for a floppy disk or **H** for a hard disk, followed by pressing <*cr*>.

5. The screen will now display the following message:

   ```
   Riso National Laboratory
   WAsP  Diskette Installation  (3.0.0)

   Diskettes MUST NOT have a write protect tab
   Please enter DRIVE letter, and hit RETURN (<--)

   Product diskette refers to the original product package diskette

   Product Diskette Drive (Input) = A<cr>
   ```

   The last line of the above message asks you for the drive where the Product Diskette (containing the WA^{S}P programme) can be found.

6. For a floppy installation the screen will then display the following message:

   ```
   Target Diskette refers to the diskette created by Install
   ...this diskette must be formatted
   Target Diskette Drive (Output) = B<cr>
   ```

   This message is asking for the drive where you wish to install the programme. If you are installing to a floppy diskette, your reply will typically be **B**, whereas if you are installing to a hard disk, it will typically be **C** or **D** (followed by pressing <*cr*>).

7. The screen will then display the following message:

   ```
   Verify Product Diskette in Drive A:
   hit RETURN (<--) to continue
   ```

   Verify that the Product Diskette is in the indicated drive, then press <*cr*>.

8. The screen will then display the following message:

```
Verify Target Diskette in Drive B:
hit RETURN (<--) to continue
```

Verify that the Target Diskette is in the indicated drive, then press <*cr*>. If the programme is installed to a hard disk this message will not be displayed.

9. The screen will then display the following message:

```
WAsP maximum install count is 0002
After this install, 0001 install(s) will be available
Enter Y to continue or N to quit, then hit RETURN (<--)
```

Press a **Y** followed by <*cr*> to continue with the installation or press **N** followed by <*cr*> to discontinue.

10. Entering **Y** the screen will display the following message:

```
Processing, please wait ...
```

While this message is displayed the computer is installing the protected version of the programme. This may take several minutes.

11. After the programme is installed, the screen will display the following message:

```
WAsP has been succesfully installed
```

This message indicates a successful installation of the programme. If any error conditions were encountered, an appropriate error message will be displayed.

Command tails

An alternative to the installation process described above is the use of command tail options. This takes the form of:

A>INSTALL⊔/F⊔T=_ ⊔P=_

where the underscore is replaced with the appropriate drive letter. Each option keyword should be separated by at least one space. The letters **T** and **P** represent the Target and Product disk drive codes. The Target disk drive can also be a hard disk. The Product disk drive is the drive where the WAsP Programme Disk is found during the installation process. A **/F** or a **/H** is used to select either floppy or hard disk installation. As an example

A>INSTALL⊔/H⊔T=C⊔P=A

will install WASP from drive A to the hard disk on drive C. Once the programme loads, follow the procedures from step 7 above.

2.2 Hints on installing and running WASP

The installation process may be automated to a certain extent. One method is to put the INSTALL utility into a BAT file, and use the command tail options to pass the drive codes and target media type. This is particularly useful when installing WASP for the first time, since the install procedure does not copy the non-protected files from the WASP Programme Diskette to the backup disk. The file COPYON.BAT performs a complete installation of WASP and its support files. Installing to a floppy diskette or a hard disk using COPYON takes the following forms:

A>**COPYON␣F␣A␣B**

A>**COPYON␣H␣A␣C**

where the WASP diskette is in drive A and the backup disk is a floppy diskette in drive B or a hard disk named C, respectively.

The WASP Data Diskette is not copy protected and may be transferred to a backup disk with the DOS command COPY *.*. This command must **not** be used to transfer the files on the WASP Programme Diskette.

For systems with PC-DOS[3] there is no difference between running a SUPERLoK protected programme and and a non-protected version of the same programme. In the same versions of MS-DOS[4] it may be necessary to enter a special code if the protected programme is loaded from a drive other than the default drive. This occurs because some versions of MS-DOS do not keep a record of the drive from which the programme was loaded. For example, if you are logged onto the A drive, and want to run WASP from the B drive, you would type the following command string (use upper-case letters only):

A>**B:WASP␣#DF=d**<*cr*>

where "d" is the drive from which WASP is loaded (in this case, it would be B). For floppy diskette loads the A drive is always searched if the programme cannot be found on the logged drive.

[3]PC-DOS is a trademark of IBM Corporation.
[4]MS-DOS is a registered trademark of Microsoft Corporation.

The language option

WA^{S}P is a menu-driven programme. The text used in the menus and in the displays in general is read by WA^{S}P from the file `WASP.TXT` on the Programme Diskette, when the programme is started. Since all the text displayed during a WA^{S}P session is collected in this file, a language option has been added to the programme. The default language is english, but by replacing the file `WASP.TXT` with another language file from the Data Diskette, the language of WA^{S}P is changed. Hence, if you type

COPY␣B:WASP.DAN␣A:WASP.TXT<*cr*>

the default language is replaced by danish. The text displayed by WA^{S}P as well as the communication between the user and WA^{S}P will now be in danish. The language files on the Data Diskette are named `WASP`, while the file extension specify the language. The extension is simply the first three characters of the english name of the language. Thus, `DAN` is used for danish, `ENG` for english, etc.

2.3 The UNinstall option

There may be times when you want to remove the installed programme from the diskette, such as when a diskette shows signs of wearing out. Likewise, you may want to move WA^{S}P from the hard disk of one computer to another. Since you can only make a limited number of copies, the UNinstall is a very useful option.

The UNinstallation procedure proceeds in much the same way as the installation procedure described in section 2.1. After points 1 and 2, the UNinstallation programme is started by typing:

A>**INSTALL␣/U**<*cr*>

In the same manner as in the install process, command tails can also be used to UNinstall WA^{S}P. The only difference is the addition of a /U option, designating the UNinstall. For example:

A>**INSTALL␣/U␣/H␣T=<u>C</u>␣P=<u>A</u>**

will UNinstall WA^{S}P to drive A from the hard disk on drive C. Once the program loads, follow the procedures from step 7 above. The UNinstallation proper may take about a minute.

2.4 Running WAsP

Once you have installed WAsP on a backup disk you may start the programme by typing:

WASP<*cr*>

A frontpage is then displayed for a few seconds, whereafter the main menu and one of the main displays are shown. The general structure of the menu "tree" of WAsP is shown in fig. 1.

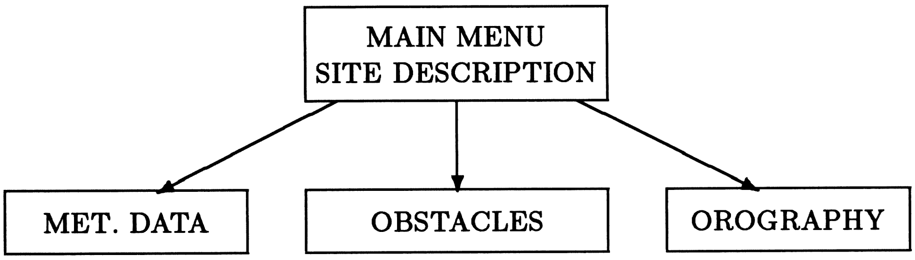


Figure 1: The menu structure of WAsP.

The main menu is shown in one of two possible displays, fig. 2. It contains keywords to enter a site description as well as to store and retrieve this. The paths to the three sub-menus are also found here. Furthermore, the windatlas model may be invoked from this menu. The models accounting for roughness change, shelter and orography are executed by entering `RETURN` or simply <*cr*>. The keywords and their usage are explained in detail in the following chapters and summarized in appendix A. Much of the information required by WAsP is entered via the keyboard and may subsequently be stored on disk files. A few options require such amounts of data input that this is not feasible and instead the data must be provided on disk file. An overview of the files recognized by WAsP is given in appendix B.

The help option

WAsP is equipped with an on-line help function that offers a brief description of the menu keywords and their usage. The help function is invoked by the `HELP` option in the various menus. In addition, you may type a "?" whenever WAsP enquires for numeric input — and most other places too. WAsP will then display a short message, stating what type of input is required. The help messages are given in the language specified by the user.

```
Wasp Airport, 1983-85
-------------------------------------------------------------------------------
Runway NW anemometer       Height  12.0 m a.g.l.              A     k       %
-------------------------------------------------------------------------------
  0: .01<  50 .07< 350 .10<                           :     3.9  2.00    2.5
 30: .01< 100 .07<                                    :     4.4  2.03    4.3
 60: .01< 150 .07<                                    :     3.8  1.89    5.7
 90: .01< 500 .07<                                    :     4.1  2.49    7.3
120: .01<1200 .07<                              *  5% :     4.3  2.41    6.3
150: .01<1000 .12<                                    :     4.5  2.28    5.4
180: .01< 500 .20<                                    :     5.1  2.13    7.7
210: .01< 400 .10<1000 .30<3000 .00<                  :     5.6  2.01    8.4
240: .01< 400 .10<1000 .30<3000 .00<6500 .10<         :     6.8  2.70   12.4
270: .01< 600 .00<5000 .10<                           :     6.7  2.47   15.5
300: .01<1000 .00<2500 .10<                           :     6.4  2.31   16.7
330: .01< 800 .00<1700 .10<                           :     4.8  1.93    7.8
-------------------------------------------------------------------------------
M=  4.9 m/s     E=  133. W/m**2                        A,k=  5.5  2.05

  RDS HEIGHT TEXT DATA ATLAS OBSTACLE OROGRAPHY WECS FREQUENCY
  DISPLAY RETURN DUMP RELOAD DOS HELP STOP
```

```
Runway NW anemometer       Height:  12.0 m. a.g.l.
-------------------------------------------------------------------------------
sect    rch       input       obstacle   orography           A     k       %
-------------------------------------------------------------------------------
  0:      2   0.0%    0deg    0.0%   -6.8%   -2deg  :     3.9  2.00    2.5
 30:      1   0.0%    0deg    0.0%   -9.3%   -1deg  :     4.4  2.03    4.3
 60:      1   0.0%    0deg    0.0%   -9.1%    1deg  :     3.8  1.89    5.7
 90:      1   0.0%    0deg   -0.5%   -6.4%    2deg  :     4.1  2.49    7.3
120:      1   5.0%    0deg  -12.8%   -3.6%    1deg  :     4.3  2.41    6.3
150:      1   0.0%    0deg   -1.8%   -4.0%   -1deg  :     4.5  2.28    5.4
180:      1   0.0%    0deg   -0.6%   -6.9%   -2deg  :     5.1  2.13    7.7
210:      3   0.0%    0deg    0.0%  -12.4%   -2deg  :     5.6  2.01    8.4
240:      4   0.0%    0deg    0.0%   -9.3%    2deg  :     6.8  2.70   12.4
270:      2   0.0%    0deg    0.0%   -4.3%    2deg  :     6.7  2.47   15.5
300:      2   0.0%    0deg    0.0%   -3.3%    1deg  :     6.4  2.31   16.7
330:      2   0.0%    0deg    0.0%   -3.8%   -2deg  :     4.8  1.93    7.8
-------------------------------------------------------------------------------
M=  4.9 m/s     E=  133. W/m**2                        A,k=  5.5  2.05

Orography: 1167 points in 31 contour lines.  Model radius : 29.853 km
Obstacles: 3 Obstacles specified.

  RDS HEIGHT TEXT DATA ATLAS OBSTACLE OROGRAPHY WECS FREQUENCY
  DISPLAY RETURN DUMP RELOAD DOS HELP STOP
```

Figure 2: Main displays of WA^SP and the main menu. The options shown are invoked typing the first three — or more — letters of the keyword.

Entering the disk operating system from WASP

You may enter and return from the Disk Operating System without terminating WASP. This feature allows you to execute DOS commands while having a WASP session. However, due to limitations in the software and/or hardware, this option has been implemented in two levels. The first level is reached by invoking the `DOS` option of the menu. You are then guided to the `DOS` sub-menu, from where you may execute several useful DOS commands. Using the commands specified in this menu should present no problem with computers and disk operating systems fulfilling the requirements for running WASP in general.

A second level is available by invoking the `DOS` option of the `DOS` sub-menu. Doing this you may subsequently enter any valid DOS command from the keyboard. The possibility of editing files that are input to WASP at a later stage in the session is a particularly useful feature of this level. To fully utilize this, your computer should have a full 640 kbytes RAM memory. This level of connection to the disk operating system may not work with some computers or versions of DOS.

3 The meteorological data input

The meteorological input to WAsP may be *raw* or *processed* data. Raw data are usually measurements of wind speed and direction, either in the form of a time-series or a climatological table. These data will reflect the specific conditions under which they were obtained. Strictly speaking, they represent only the exact point of measurement. In order to extrapolate such data, one must take into account the surface roughness conditions, the effect of nearby obstacles and the effect of the terrain characteristics at the meteorological station. Only after "cleaning" the data in this way can they be used for estimating the wind climate at other places around the meteorological station. By processed data we mean data for which this kind of analysis has already been performed, leading to a windatlas for the region considered. The windatlas gives the probability density function (Weibull distribution) of wind speed for certain standard conditions, i.e. standard azimuth sectors, heights above ground and surface roughness conditions.

This chapter outlines the ways to enter and store meteorological data. The routines to handle data input and output are collected in the `DATA` sub-menu of WAsP:

```
Keywords:  RAWDATA LIBRARY TABLE ATLAS ARCHIVE DOS HELP RETURN
```

The meteorological data are stored on sequential ASCII disk files. However, input of time-series data is also possible from binary files.

3.1 Time-series data

Time-series data may be entered to WAsP by invoking the `RAWDATA` option in the `DATA` sub-menu. The input is an ASCII or binary file[5] containing one observation of wind speed and direction per record. Having entered the file name (default filename extension `.DAT`), WAsP will ask for the format of the data records. Blank input (<*cr*>) is required for binary files, and any valid FORTRAN 77 format character expression for ASCII files (e.g. 8X,2I3). An asterisk (*) is given for free-format input.

Next, lower and upper limits for wind speed (u) and direction (d) must be specified. The data are divided into three groups on the basis of these limits: *dummy values*, *calms* and *wind observations*. A fourth group of observations are *reading errors*. Definition of these four types of data is given in table 1.

[5] As binary files are processed much faster and often require less disk space than ASCII files, it is recommended to convert time-series data before running WAsP. A separate programme – `CONVERT.EXE` – on the Data Diskette performs this task.

dummy values	$d < d_{min}$ or $d > d_{max}$ or $u < 0.0$ or $u > u_{max}$
reading errors	non-numeric input in record
calms	$0.0 \leq u < u_{min}$
wind observations	$u_{min} \leq u \leq u_{max}$

Table 1: Observation types recognized by WAsP.

Note that the criteria given in the table are applied to the data as given in the file. Dummy values and reading errors are considered missing observations and only wind observations and calms are treated further in the data processing.

WAsP offers the possibility of scaling the data linearly if the wind measurements are not given in $[ms^{-1}]$ and $[deg]$, or the data needs recalibration. A scaling factor and an offset can be specified for both wind speed and direction and are applied in the following way

$$X_{new} = \textit{scaling factor} \times X_{old} + \textit{offset} \tag{1}$$

where X is either wind speed or direction.

WAsP reads the data file, dividing the observations into 50 classes of wind speed and 12 classes of wind direction. The speed classes have a bin width of 1 ms^{-1} and are defined[6] as

$$1 : [0,1[, \ 2 : [1,2[, \ 3 : [2,3[, \ \ldots \ , \ 50 : [49,\infty[\tag{2}$$

Classes of azimuth are 30 degrees wide and defined as

$$1 : [345,15[, \ 2 : [15,45[, \ 3 : [45,75[, \ \ldots \ , \ 12 : [315,345[\tag{3}$$

Having processed the data file, WAsP displays a summary of the observations, figure 3. Note that calms are included in the table, distributed evenly over the sectors. As an aid in evaluating the data quality, a Weibull distribution function is fitted to the observations in each sector. The calculated Weibull A and k parameters for each sector is also shown in figure 3.

The resulting histogram can be stored on disk file at this stage (`DUMP` option), to avoid processing the time series again. Sample ASCII and binary data files

[6]Square brackets are used in the following sense: $[2,3[$ is identical to $2 \leq x < 3$.

and the corresponding histogram file are supplied on the WA^{S}P Data Diskette as `RAWDATA.ASC`, `RAWDATA.DAT` and `WASPDALE.TAB`, respectively.

```
Summary of data in file : RAWDATA.DAT                                 [per mille]
Number of observations  :  8760        Observations skipped :    244
Number of reading errors:     0        Wind speed bin width :    1.0
```

Sect	Freq	<1	2	3	4	5	6	7	8	9	11	13	15	17	>17	A	k
0:	2.0	48	198	287	144	186	114	24	0	0	0	0	0	0	0	3.5	2.10
30:	4.4	42	93	188	246	172	114	48	71	19	8	0	0	0	0	4.4	2.00
60:	5.6	27	165	240	276	134	65	44	27	13	10	0	0	0	0	3.8	1.87
90:	7.5	41	118	215	251	205	118	38	14	2	0	0	0	0	0	4.0	2.63
120:	6.2	30	118	194	229	211	137	38	26	11	4	0	0	0	2	4.3	2.47
150:	5.3	51	78	164	257	215	142	44	18	9	18	2	0	0	2	4.4	2.29
180:	7.8	27	50	123	227	218	175	84	29	27	33	6	0	0	0	5.1	2.21
210:	8.4	24	60	117	169	138	127	133	105	59	46	20	1	0	0	5.9	2.21
240:	12.2	14	25	53	110	151	146	153	138	85	105	17	3	0	0	6.9	2.78
270:	15.7	14	36	56	140	134	133	152	111	78	103	36	6	2	2	6.9	2.38
300:	16.8	13	52	81	140	143	161	165	91	59	72	16	2	1	3	6.3	2.34
330:	8.1	13	85	194	213	162	111	98	54	36	32	3	0	0	0	4.8	1.93
Total		23	71	128	184	164	135	108	73	45	52	13	2	1	1	5.5	1.97

```
Number of calms (included):      0              Mean wind speed :   4.9    m/s

  DUMP DOS RETURN
```

Figure 3: Summary display of the `RAWDATA` option. The frequencies of occurrence are normalized sector-wise in per mille.

3.2 General climatological data

At most meteorological stations the observation series are compiled routinely into climatological tables, that provide a statistical summary of the measured time series. Such tables will usually be the only readily available information on the wind climate at a certain station. Consequently, WA^{S}P has been equipped with routines to read and write this type of data — the `TABLE` option of the `DATA` sub-menu. Tables giving the frequency of occurrence of wind speed versus wind direction are of primary interest in this context. It should be borne in mind, that even though the data have been processed statistically, they still constitute raw data and must be treated accordingly.

Before invoking the `TABLE` option, a disk file containing the climatological table as well as some additional information should be prepared. A sample histogram file is shown in fig. 4.

```
Wasp Airport 1983-85. Runway NW anemometer.
     -55.70      -167.90        12.00
         12         1.00         0.00
        2.0   4.4   5.6   7.5   6.2   5.3   7.8   8.4  12.2  15.7  16.8   8.1
  1.00   48    42    27    41    30    51    27    24    14    14    13    13
  2.00  198    93   165   118   119    78    50    60    25    36    52    85
  3.00  287   188   240   215   194   164   123   117    53    56    81   194
  4.00  144   246   276   251   230   258   227   169   110   140   140   213
  5.00  186   172   134   205   211   216   218   138   151   134   143   162
  6.00  114   114    65   118   137   142   175   127   146   133   161   111
  7.00   24    48    44    38    38    44    84   133   153   152   165    98
  8.00    0    71    27    14    26    18    29   105   138   111    91    54
  9.00    0    19    13     2    11     9    27    59    85    78    59    36
 10.00    0     5     2     0     4    13    15    27    59    56    42    20
 11.00    0     3     8     0     0     4    18    20    46    47    30    12
 12.00    0     0     0     0     0     2     5     8    13    21    10     1
 13.00    0     0     0     0     0     0     2    11     4    15     6     1
 14.00    0     0     0     0     0     0     0     1     2     6     1     0
 15.00    0     0     0     0     0     0     0     0     1     0     1     0
 16.00    0     0     0     0     0     0     0     0     0     1     1     0
 17.00    0     0     0     0     0     0     0     0     0     2     0     0
 18.00    0     0     0     0     0     0     0     0     0     1     1     0
 19.00    0     0     0     0     0     0     0     0     0     0     1     0
 20.00    0     0     0     0     0     0     0     0     0     1     1     0
 21.00    0     0     0     0     0     0     0     0     0     0     1     0
```

Figure 4: Sample histogram file (`WASPDALE.TAB`).

Referring to figure 4, *line 1* is a character string identifying the contents of the file. *Line 2* gives the latitude and longitude of the station and height above ground level of the anemometer. Conventionally, latitude N and longitude[7] E are considered positive. *Line 3* states the number of sectors, a scaling factor for wind speed and an offset for direction. The scaling factor is used to convert the given wind speed class limits to $[ms^{-1}]$. The offset angle serves to rotate the user frame of reference, so as to center the first sector given in the table on 0 degrees (north). *Line 4* gives the frequencies of occurrence in per cent, of winds in the various sectors. *Line 5* and onward contains the climatological table, each line corresponding to one wind speed class. First, the upper limit of the speed class is given, then follow the frequencies of occurrence of this class in the sectors. A maximum of 50 speed classes can be specified. The frequencies may be normalized sectorwise as in fig. 4, or may be given in absolute units. In the latter case line 4 of the file should contain non-numeric input instead of frequencies. Note that the format of the file is free, i.e. numbers must be separated by a comma or one or more blank characters (spaces).

[7]The longitude is not used for calculations by WA^{s}P and may be set to any number.

In case the table summarizes upper-air observations, the height of observation in line 2 should be set to some non-numeric input like "*" or "radiosonde data". The table is then regarded as statistics for the geostrophic wind.

Having prepared the histogram file the TABLE option may be invoked. WAsP will then enquire whether to read or write[8] a file. Choose to read and then enter a filename — a default file extension of .TAB is assumed by WAsP. Returning to one of the main displays observe that the table is not yet in effect. For this to happen you must explicitely have executed the windatlas model by invoking the ATLAS option (see section 7).

3.3 Windatlas data

Windatlas data are truly processed data in the sense that the wind statistics at a given station have been "reduced" to certain standard conditions. As such, they are the natural meteorological basis for a wind turbine siting project. Unfortunately, only few regions of the world are covered by windatlas data. The Danish Windatlas (Petersen *et al.*, 1981) is supplied with WAsP now (DENMARK.LIB on the Data Diskette), and a windatlas covering most of Europe will be available soon (Petersen and Troen, 1986). However, the results of a WAsP session can be stored as windatlas files, providing the user with means of establishing his own library of windatlas data for the region of interest.

Input and output of windatlas data are taken care of by the LIBRARY and ARCHIVE options, respectively, in the DATA sub-menu. A sample windatlas file is provided on the WAsP Data Diskette as WASPDALE.LIB. This file is the result of a WAsP session using the sample data provided on the same diskette. The contents of the file are shown schematically in table 2.

[8]The purpose of the write choice is to let you save the histogram of a time-series processing, should you have forgotten it leaving the RAWDATA option.

Line	Contents
1	Character string identifying the table
2	Number of roughness classes, heights and sectors
3	The standard roughness lengths: 0.0002, 0.03, 0.1 and 0.4 $[m]$
4	The standard heights: 10, 25, 50, 100, 200 $[m]$ a.g.l.
5	The frequencies of occurrence: **roughness class 0**
6	Weibull A parameters for 10 m $[ms^{-1}]$
7	Weibull k parameters for 10 m
8-9	Weibull A and k parameters for 25 m
10-11	Weibull A and k parameters for 50 m
12-13	Weibull A and k parameters for 100 m
14-15	Weibull A and k parameters for 200 m
16-26	As line 5-15, but for **roughness class 1**
27-37	As line 5-15, but for **roughness class 2**
38-48	As line 5-15, but for **roughness class 3**

Table 2: Contents of a windatlas file, cf. `WASPDALE.LIB` on the WAsP Data Diskette.

4 Describing a site

In order for WA^{S}P to calculate the effects on the wind of the surroundings at a given place ("the site") it is necessary to describe systematically the characteristics of the surroundings. The site may be a projected wind turbine site or a meteorological station.

The overall action on the wind of the underlying surface is generally referred to as the roughness of the terrain. However, not all the topographical elements contribute to the roughness. Vegetation and houses are examples of roughness elements, whereas long smooth hills, for example, are not, because they do not themselves cause an increase in the turbulence of the flow.

Orographic elements such as hills, cliffs, escarpments and ridges exert additional influence on the wind. Near the summit or crest of these features the wind will be accelerated while near the foot and in valleys it will be decelerated.

The wind close to an obstacle such as a building is strongly influenced by the presence of the building. The effect extends up to approximately three times the height of the building and 30 to 40 times the height downstream. If the point of interest is inside this zone it is necessary to take the sheltering effects into account, whereas if the point is outside the zone the building is treated as a roughness element.

For a given situation we have three main effects on the wind from topography: roughness, shelter and orographic effects. In nature these effects are not entirely independent. The programme takes this into account, but allows the user to specify the roughness of the surrounding terrain, the close-by sheltering obstacles and the orography independently. How these terrain characteristics are obtained and entered to WA^{S}P will be explained in this and the following two chapters.

Practical considerations. When it comes to describing a site in practice it is recommended that the following material is available:

- a recently revised topographical map of scale 1:25,000 or 1:50,000 preferably with height contour lines.

- a map or sketch showing sheltering obstacles close to the point of interest.

- a transparency with 12 sector divisions.

A protractor of the nautical plotter type, capable of measuring both the azimuth angle and the distance from the origin, may be useful too.

4.1 Measures of terrain roughness

The roughness of a terrain is parameterized through the roughness length z_0, a quantity treated extensively in the micro-meteorological literature. Formally, z_0 is the height where the mean wind speed becomes zero if the wind profile has a logarithmic variation with height. This usually occurs during moderate and strong wind conditions.

The roughness of a particular surface is determined by the size and distribution of the "roughness elements", i.e. for land surfaces typically vegetation, built-up areas and the soil surface. The geometry and physical characteristics of the various roughness elements also play an important role. Basically, a roughness element can be characterized by its height h, the cross section facing the wind S, and a porosity to the wind. Further, for a population of roughness elements distributed evenly over an area, their density can be described by the horizontal area, A_H, available for each on the average. Through a series of experiments, a simple empirical relation among the above-mentioned characteristics was established by Lettau (1969):

$$z_0 = 0.5 \times \frac{h \times S}{A_H} \tag{4}$$

This relation gives reasonable estimates of z_0 when A_H is much larger than S; it tends to overestimate z_0 when A_H becomes of the order of S. Furthermore, it assumes that the porosity is approximately zero, i.e. that the roughness elements are solid.

<u>Example.</u> As an application of equation (4) we may calculate the roughness of a terrain with a large number of houses (provincial town). The roughness is estimated from $h = 5\ m$, $S = 100\ m^2$ and $A_H = 1000\ m^2$:

$$z_0 = 0.5 \times 5 \times \frac{100}{1000} = 0.25\ m \tag{5}$$

i.e. the resulting $z_0 \approx 25\ cm$.

The empirical relation may also be applied to windbreaks (shelter belts) by letting $S \sim hL$ and $A_H \sim \ell L$, where L is the length of the windbreak and ℓ the distance between the windbreaks:

$$z_0 = 0.5 \times \frac{h^2}{\ell} \tag{6}$$

For a typical height of 10 m, the influence on z_0 of ℓ can be illustrated by the following table:

ℓ	$[m]$	1000	500	200
z_0	$[m]$	0.05	0.1	0.25

Note that this result was obtained assuming a porosity of zero. For windbreaks of trees and bushes the porosity is approximately 0.5 leading to a decrease in the distance ℓ between the windbreaks of a factor of two for the same roughness.

Roughness classes

For the purpose of wind atlas calculations the landscape can often be divided into roughness classes. A description and illustration of the four roughness classes used in the Danish Windatlas (Petersen *et al.*, 1981) is given below. Figure 5 provides a quick reference to the relation between roughness length, terrain characteristics and roughness class.

Roughness class 0. Water areas: The sea, fjords and lakes.

Roughness class 1. Open areas without significant windbreaks: The terrain appears to be very open because there are only very few windbreaks, if any. The terrain is flat or very gently rolling. Single farms and stands of low bushes can be found. Figure 6 shows examples of this roughness class.

Roughness class 2. Farmland with windbreaks with a mean separation in excess of 1000 m, and some scattered built-up areas: The terrain is characterized by large open areas between the many windbreaks, giving the landscape an open appearance. The terrain may be flat or strongly undulating. Trees and buildings are common. Examples of this roughness class are given in fig. 7.

Roughness class 3. Urban districts, forests, and farmland with many windbreaks: The farmland is characterized by the many closely spaced windbreaks, the average separation being a few hundred meters. Forest and urban areas also belong to this class, of which an example is given in fig. 8.

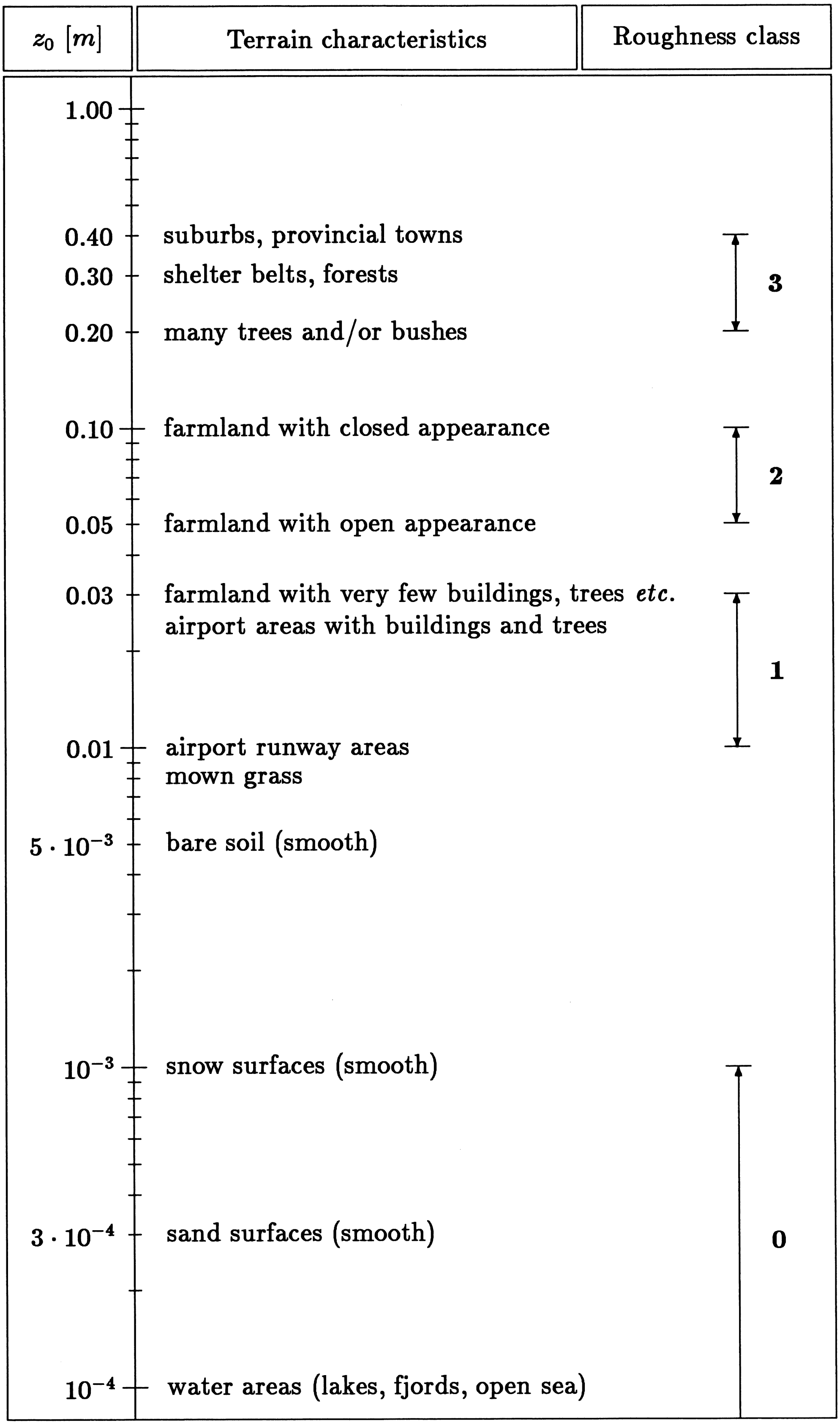
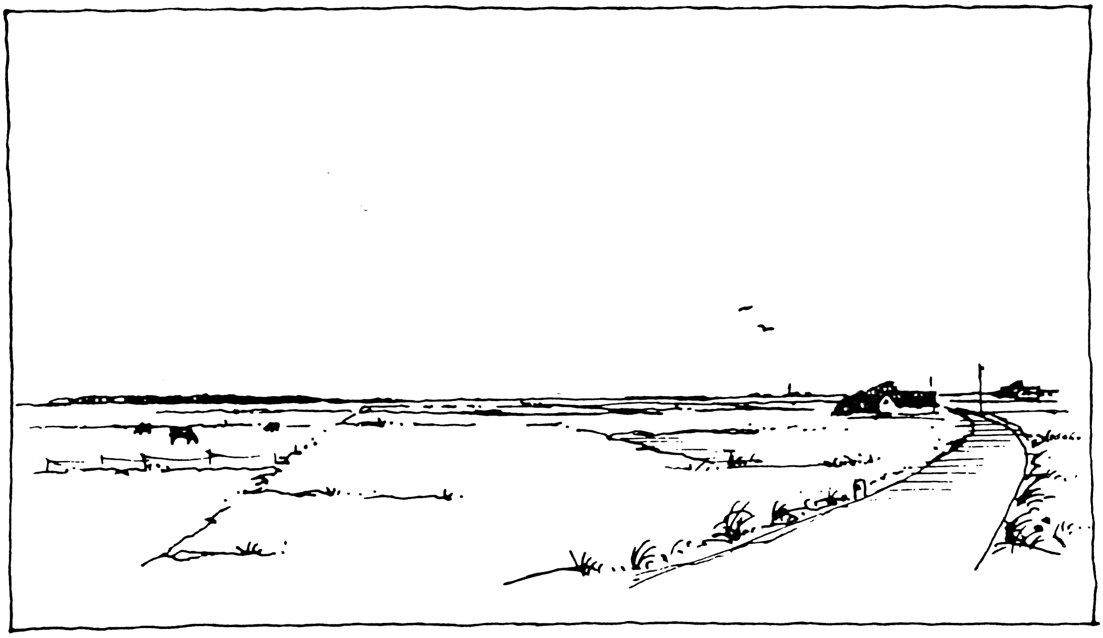


Figure 5: Roughness length, terrain characteristics and roughness class.



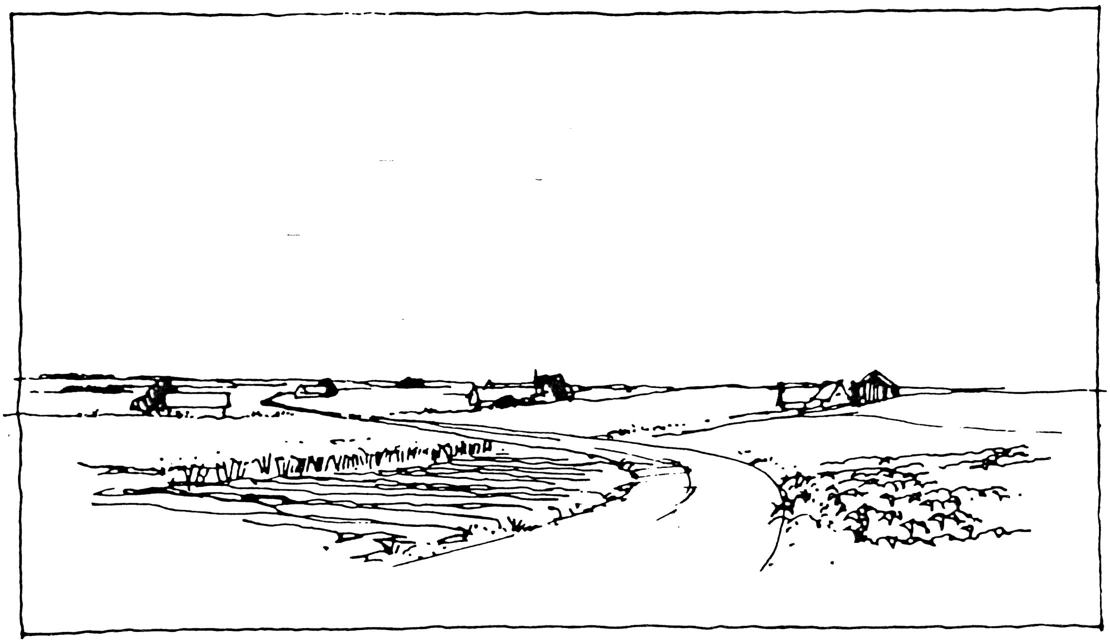


Figure 6: Examples of terrains corresponding to roughness class 1 (drawing by S. Rasmussen).

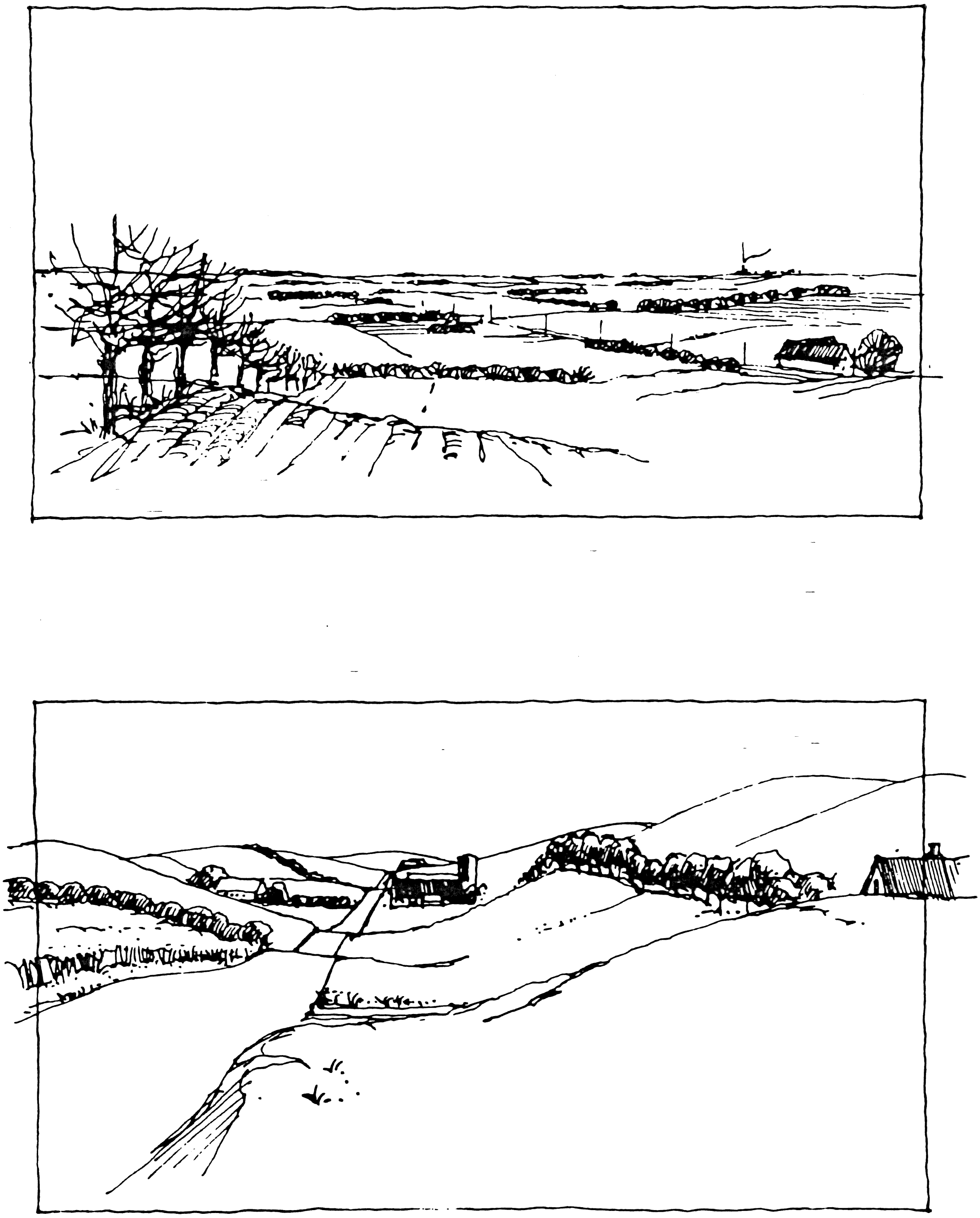


Figure 7: Examples of terrains corresponding to roughness class 2 (drawing by S. Rasmussen).

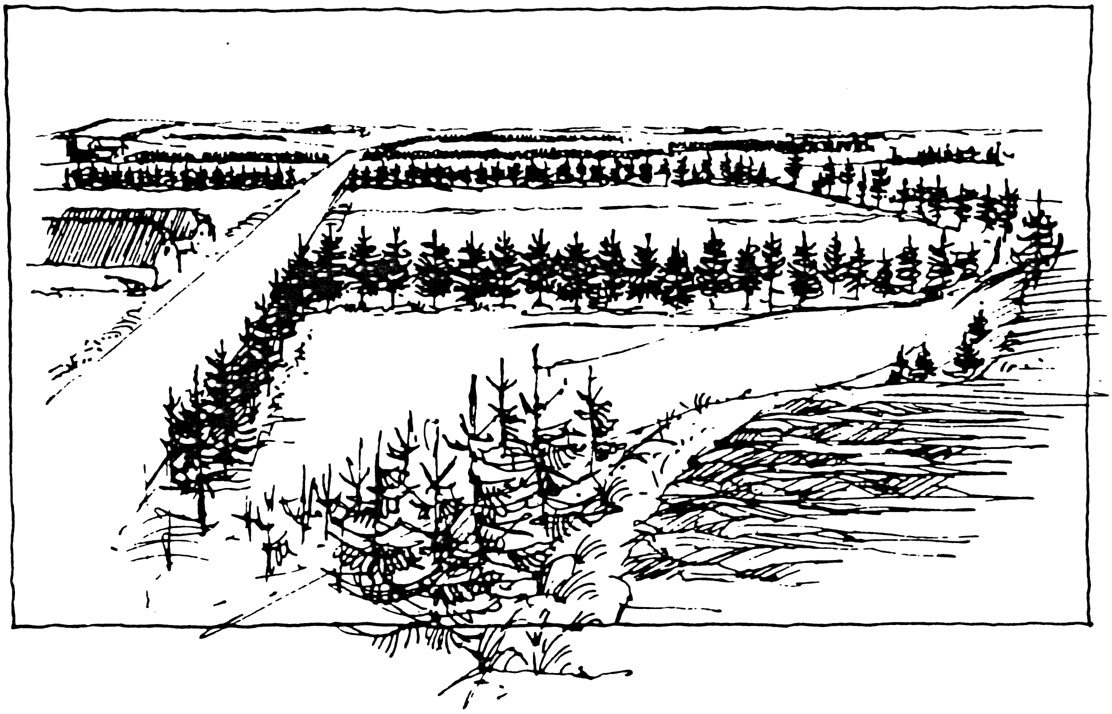


Figure 8: Example of a terrain corresponding to roughness class 3 (drawing by S. Rasmussen).

4.2 Roughness classification

The roughness classification of the terrain surrounding a given site is in its most simple form a matter of assigning proper roughness lenghts to the various surface types around the site. Dividing the horizon in twelve 30-degree sectors, the classification is done sector by sector after the following principles:

1. The classification shall extend to at least 5 km from the site. If there are extensive water surfaces further away it may even be extended to 10 km or more.

2. In case there are several roughness changes in a sector the following rule may be applied: Let X_1 be the distance from the site to the first roughness change, X_2 the distance to the next, and X_n the distance to roughness change number n. Then,

$$X_n \geq 2X_{n-1}, \quad n = 2, \ldots ; n \leq 10 \tag{7}$$

This guideline should be adhered to in order to avoid an abundance of roughness changes. A maximum of ten can be specified in each sector.

3. In case the terrain between two lines of roughness change is not uniform a resulting roughness, z_0^R, must be estimated. Dividing the segment into quarters of approximately equal roughness, table 3 gives the overall roughness length of the segment as a function of the number of quarters of each roughness class in the segment.

   This division of the sector segment has to be done keeping in mind that areas close to the site will exert the strongest influence on the wind speed at the site. By using the principle of fig. 9 high weights are assigned to close-by areas when each of the areas I, II, III and IV are given the same weight. Hence, if area I, II, III and IV are of class 0, 1, 2 and 3, respectively, the resulting roughness derived from table 3 is ≈ 0.04 m.

The roughness classification may be noted down on a separate sheet like the "Roughness Classification Form" provided in appendix C.

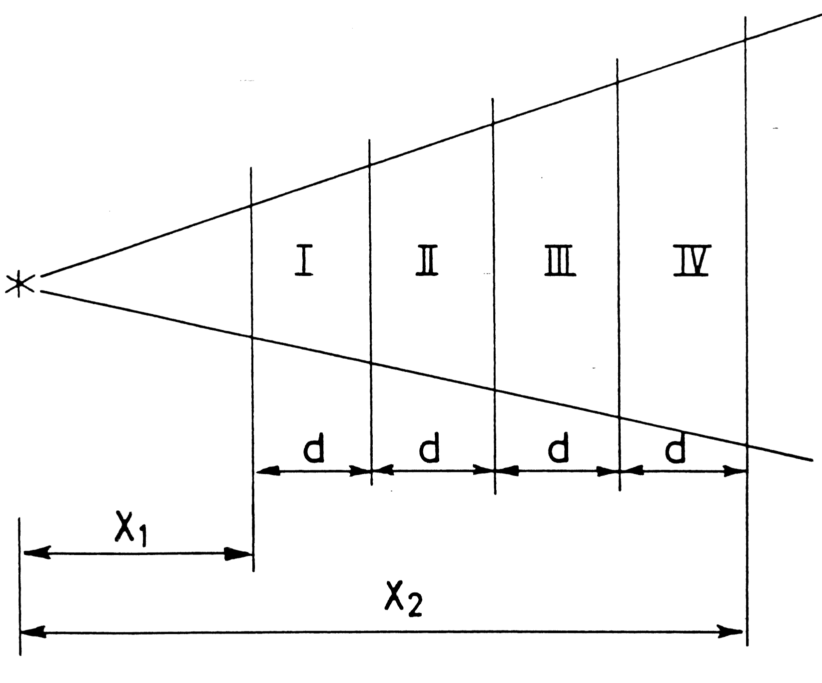


Figure 9: Principle of weighting areas in roughness calculations.

Example. In fig. 10 a likely set-up for a meteorological mast at an airport is shown. The anemometer is situated between the runways about 600 m from the border of the airport. The first roughness change, from class 1 to class 3, appears at the airport fence. The forest outside the airport has an irregular shape, but choosing the next change 1200 m from the site, in accordance with the rules set forth above, seems reasonable. The next change should then not be closer to the site than 2400 m. A choice of 2600 m makes good sense as the terrain here changes to class 2, this class extending far away from the site. For the segment between roughness change two and three table 3 gives an overall roughness length of ≈ 0.01 m, corresponding to two quarters of class 0, one quarter of class 1 and one quarter of class 3.

Class:	0	1	2	3	z_0^R
z_0 [m]:	0.0002	0.03	0.10	0.40	[m]
	3	1			0.001
	3		1		0.002
	3			1	0.003
	2	2			0.004
	2	1	1		0.006
	2	1		1	0.010
	2		2		0.009
	2		1	1	0.015
	2			2	0.025
	1	3			0.011
	1	2	1		0.017
	1	2		1	0.027
	1	1	2		0.024
	1	1	1	1	0.038
	1	1		2	0.059
	1		3		0.033
	1		2	1	0.052
	1		1	2	0.079
	1			3	0.117
		3	1		0.042
		3		1	0.064
		2	2		0.056
		2	1	1	0.086
		2		2	0.127
		1	3		0.077
		1	2	1	0.113
		1	1	2	0.163
		1		3	0.232
			3	1	0.146
			2	2	0.209
			1	3	0.292

Table 3: Area weighted roughness lengths, z_0^R. The area is divided into quarters and each quarter is classified according to the EEC Windatlas roughness classification. z_0^R is given as a function of the number of quarters of each roughness class in the area.

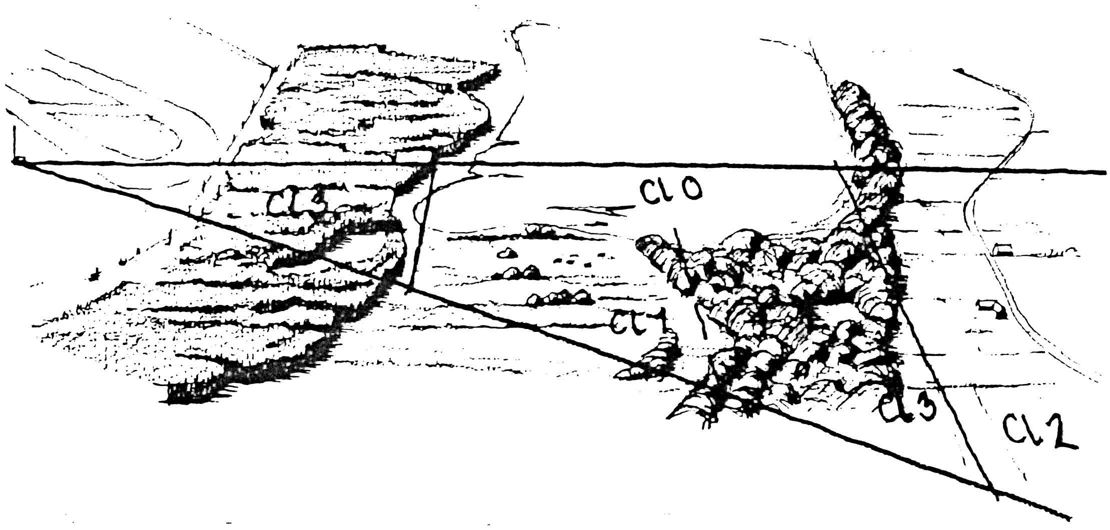


Figure 10: Roughness classification — an example (drawing by S. Rasmussen).

4.3 Local effects

At this point in the site description you may also want to note down strictly "local" influences on the wind measurements. The word local is used here for effects that cannot easily be classed with roughness, shelter or orography; or effects that – by experience or experiment – are known to the user. If, for example, the shadowing effect of a wind vane mounted beside the anemometer is known to reduce the wind speed in certain sectors, the amount of reduction is noted in the "Roughness Classification Form". This is timely because effects of this kind are entered together with the roughness description when running WAsP.

4.4 Entering the site description

Having classified the roughness of areas adjacent to the site and noted this and possible local effects on the "Roughness Classification Form" you may invoke the RDS option of the main display. The site description is entered from the keyboard using the following syntax:

$$d_i[-d_j] : [< \textit{roughness description} >][*p_{user}][\mathrm{T}\Delta d_{user}] \tag{8}$$

where $d_{i,j}$ is the center angle of a sector, p_{user} is the local or user-specified percentage change of wind speed and Δd_{user} is a user-specified turning of the wind direction. Square brackets indicate an optional parameter. The roughness description is typed as:

$$< \textit{roughness description} >= z_{01}[, X_1, z_{02}[, X_2, z_{03} \ldots [X_{n-1}, z_{0n}] \tag{9}$$

where $n \leq 10$, and the roughness length z_0 and the distance X, are given in metres. The following lines are examples of valid input:

$$\begin{array}{rcl} \mathtt{180} & : & \mathtt{0.01, 500, 0.20} \\ \mathtt{120} & : & \mathtt{0.01, 1200, 0.07} * \mathtt{5} \\ \mathtt{300} - \mathtt{330} & : & \mathtt{0.06, 500, 0.10, 1200, 0.40, 3000, 0.10} * \mathtt{6T4} \end{array} \tag{10}$$

The site description further consists of the height for which the calculations are performed and a text identifying the description. These parameters are shown in the main display above the roughness description and may be changed with the `HEIGHT` and `TEXT` options, respectively. Note that only the first four roughness changes are displayed on the screen. The total number of roughness changes and the user-specified corrections for each sector are given in the other main display.

Once the complete site description has been established it may be stored on, and retrieved from, disk file using the `DUMP` and `RELOAD` options of the main menu. The contents of a site description file appear from table 4.

Line	Contents
1	Character string identifying the description
2	Current height of WA^{S}P [m]
3	User-specified correction factors for wind speed
4	User-specified correction angles for direction [deg]
5	Number of roughness changes in each sector
6	Roughness lengths [m] of sector 1–6
7	Roughness lengths [m] of sector 7–12
8	Distances [m] to first roughness change, sector 1–6
9	Distances [m] to first roughness change, sector 7–12
	Roughness lengths and distances written in a similar way as in line 6–9 are repeated as many times as the maximum number of roughness changes specified.

Table 4: Contents of a site description file, cf. `AIRPORT.RDS` on the WA^{S}P Data Diskette.

5 Shelter identification

Shelter is defined as the relative decrease in wind speed caused by an obstacle in the terrain. Whether an obstacle provides shelter at the specific site depends upon:

- the distance from the obstacle to the site.
- the height of the obstacle compared to the height of the point of interest.
- the length of the obstacle.
- the porosity of the obstacle.

Figure 11 shows the reduction of wind speed due to shelter from an infinitely long two-dimensional obstacle of zero porosity. The shelter decrease with diminishing length and increasing porosity of the obstacle. Figure 11 may serve as a guideline for including obstacles in the terrain as sheltering obstacles. However, if in doubt one should include the obstacle — WA^{S}P can handle up to 50 obstacles at the same time.

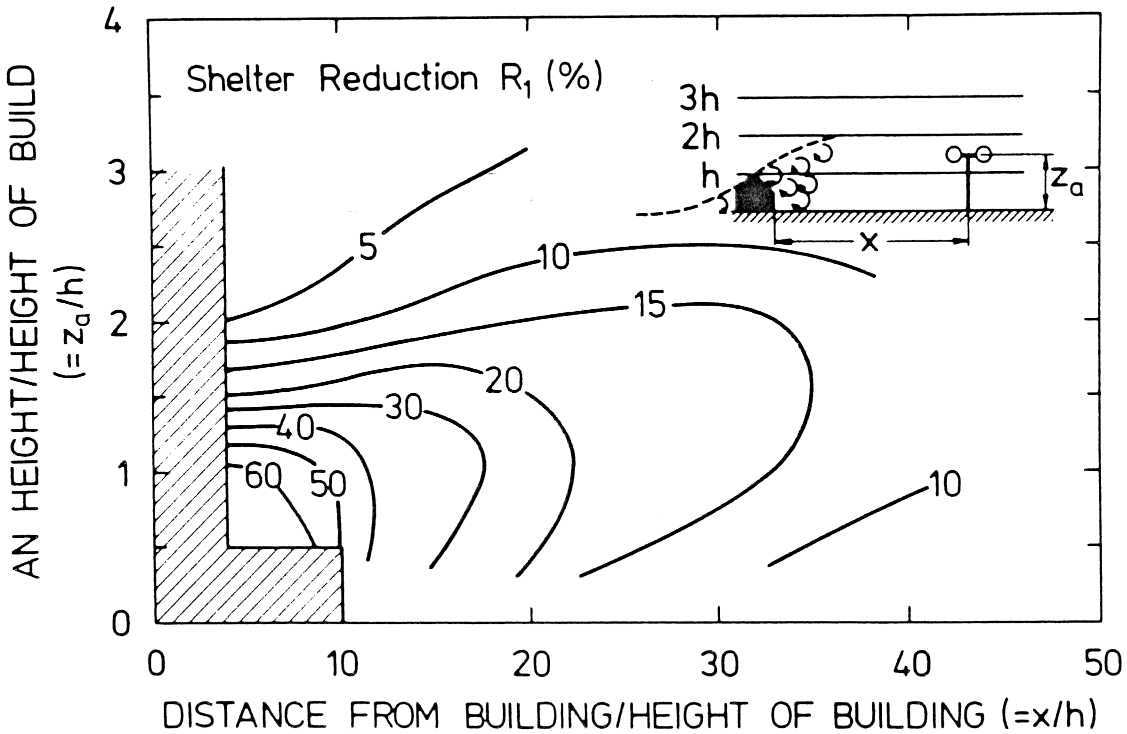


Figure 11: Reduction of wind speed due to shelter by two-dimensional obstacle. Based on the expressions given by Perera (1981).

The porosity can generally be set equal to zero for buildings and ≈ 0.5 for trees. A row of similar buildings with a separation between them of one third of the building length will have a porosity of about 0.33. For windbreaks the following characteristics may be applied:

Appearance	Porosity
Solid (wall)	0
Very dense	≤ 0.35
Dense	$0.35 - 0.50$
Open	≥ 0.50

Table 5: Porosity of windbreaks

For trees the porosity change with foliation i.e. the time of the year. The roughness has a seasonal variation too, but it should be kept in mind that the calculations performed by WA^{S}P provide climatological statistics. Hence, both the roughness length and the porosity should be considered climatological parameters.

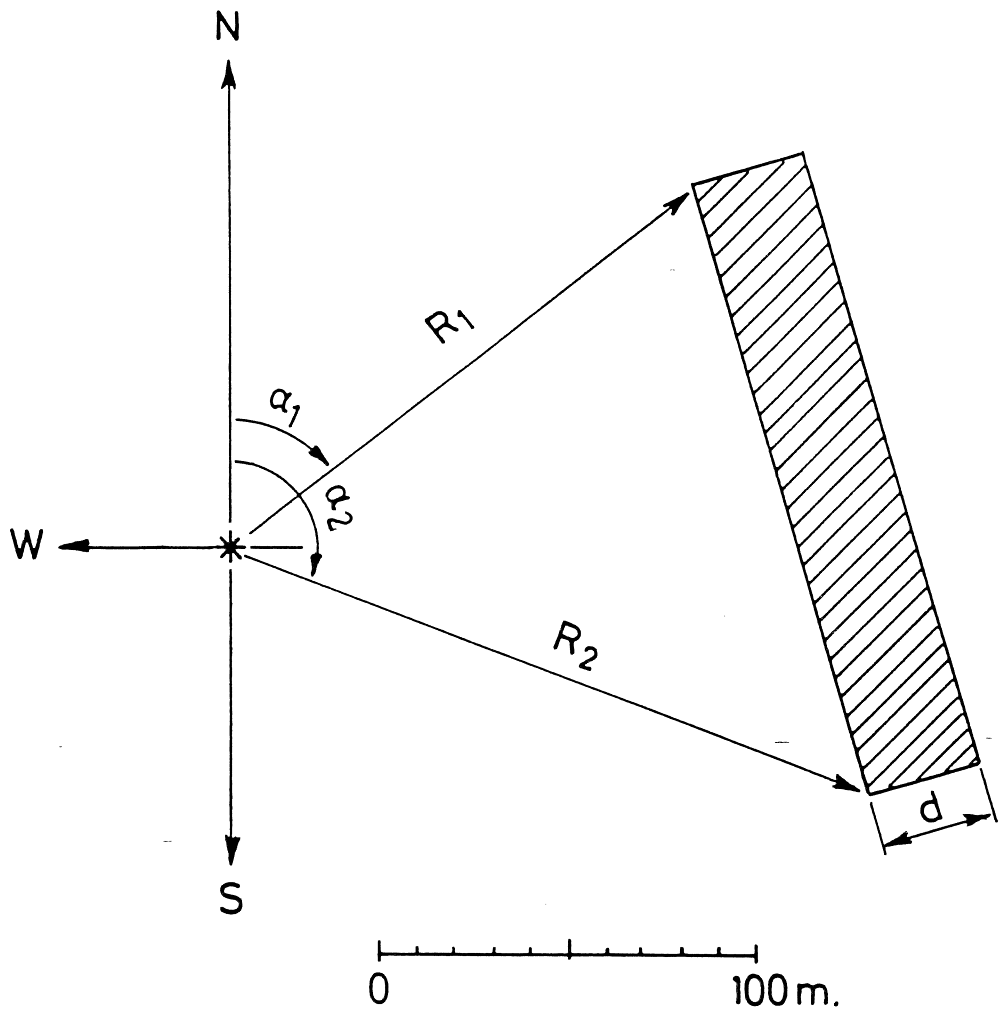
Further, it should be noted that if one or more obstacles are treated as sheltering obstacles they should not at the same time be considered roughness elements.

5.1 Providing the obstacle description

Obstacles are considered by WA^{S}P as "boxes" with a rectangular cross-section. Each obstacle must be specified by the position relative to the site, its dimensions and must be assigned a porosity. Figure 12 defines the quantities that specify a single obstacle and that must be input to WA^{S}P. The information may be noted down on a separate sheet like the "Obstacle Description Form" provided in appendix C.

Example. Figure 13 depicts the anemometer conditions at Rolunde Airport, Denmark, and fig. 14 shows the completed "Obstacle Description Form".

Occasionally, some sheltering or "shadowing" effects are known quantitatively from measurements at the site or perhaps from wind tunnel experiments. Such knowledge may be supplied to WA^{S}P directly through the site description — see section 4.3. This feature may also be used to account for effects of obstacles very close to the site, say closer than a few obstacle heights. In this case the shelter model may not give entirely realistic results.



*	site position
α_1	angle from N to first corner $[deg]$
R_1	radial distance to first corner $[m]$
α_2	angle from N to second corner $[deg]$
R_2	radial distance to second corner $[m]$
d	depth of obstacle $[m]$
h	height of obstacle $[m]$
type	building, row of trees, dense thin estimated porosity

byt om!

Figure 12: Providing shelter information. Angles are measured from 0 to 360 degrees clockwise. First and second corner refers to that side of the obstacle facing the anemometer (site).

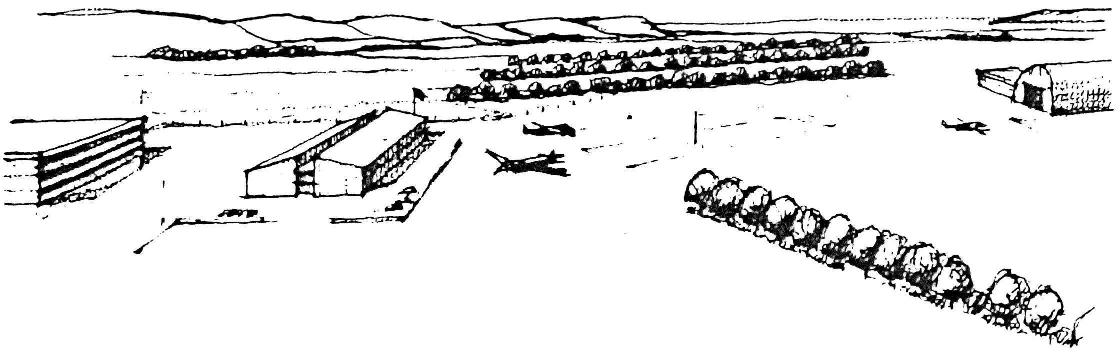


Figure 13: Example showing a configuration of various sheltering obstacles (Rolunde Airport). The corresponding "Obstacle Description Form" is shown in fig. 14.

5.2 Entering a list of obstacles

Input of and editing a list of obstacles for a specific site is taken care of by the OBSTACLE sub-menu:

```
Keywords: INPUT EDIT MOVE CLEAR DUMP RELOAD DOS HELP RETURN
```

Invoking the INPUT option obstacles may be entered one by one, the information typed in the same order as given in the description form (fig. 14). The EDIT option lists the obstacles specified in the current set-up and allows you to change the characteristics of one or more obstacles. Deleting an obstacle is done by entering the number of the obstacle only. Extending the list may be done in either INPUT or EDIT mode. Once the obstacle list is established it may be stored on — and retrieved from — disk file using the DUMP and RELOAD options, respectively. A default filename extension of .OBS is assumed by WA^{S}P.

In case there are more than one site of interest close to a given set-up of obstacles, these need only be specified and typed in once. The MOVE option recalculates the obstacle descriptions relative to a new site. Finally, CLEAR clears the obstacle list from the scenario.

The shelter model is executed each time the main display is refreshed by entering a <*cr*>. One of the main displays shows the number of obstacles currently specified and further gives the reduction of wind speeds in the various sectors due to the shelter effects.

OBSTACLE DESCRIPTION FORM

Station: *Rolunde Airport, DK–17* Date: *1985*

byt om

#	α_1	R_1	α_2	R_2	d	h	type
1	*11*	*134*	*26*	*120*	*30*	*12*	*building*
2	*26*	*120*	*43*	*110*	*60*	*6*	*building*
3	*112*	∞	*146*	*74*	*16*	*5*	*rows of trees, dense*
4	*200*	*90*	*248*	*76*	*26*	*8*	*building*
5	*215*	*154*	*237*	*144*	*46*	*6*	*building*
6	*278*	*116*	*352*	*150*	*6*	*6*	*row of trees, thin*
7	*295*	*150*	*345*	*196*	*6*	*6*	*row of trees, thin*
8	*305*	*196*	*341*	*250*	*6*	*6*	*row of trees, thin*

α is given in degrees from north and R in metres.

Additional information:

Obstacle # 3 extends 1500 m away from the station, the trees are birch trees and there are dense low bushes.

Obstacles # 7–8 are thinly spaced pine trees.

Figure 14: Obstacle description for Rolunde Airport (see fig. 13).

6 Winds in complex terrain

WA^{S}P utilizes the "BZ" model of Troen (1987) to calculate the wind velocity perturbations induced by orographic features such as single hills or more complex terrain. The BZ model belongs to a family of models related to the Jackson and Hunt theory for flow over hills (Jackson and Hunt, 1975; Taylor *et al.*, 1983). The model was developed with the specific purpose of detailed wind energy siting in mind and has the following general features:

- It employs a high-resolution, zooming, polar grid. This is coupled with a map analysis routine in order to calculate the potential flow perturbation profile at the central point of the model.
- It integrates the roughness conditions of the terrain surface into the spectral or scale decomposition. The "inner-layer" structure is calculated using a balance condition between surface stress, advection and the pressure gradient.
- It uses an atmospheric boundary layer thickness of $\approx$ 1 km to force the large scale (say, more than a few kilometers) flow around high-altitude areas.

The sections to follow describe how to obtain the input required by the model.

6.1 The digitized map

The orographic basis for the complex terrain flow model of WA^{S}P is a digital height contour map. The terrain described in this may be "real" or an idealized one. The digital map consists of strings of coordinate pairs, each string specifying one height contour line. The coordinates may be given either in a Cartesian coordinate system (x, y) or a polar system (r, θ).

When planning the provision of the digital map one should take the following points into consideration:

- A maximum of 10,000 points in 200 contour lines is allowed to describe the terrain around the site.
- WA^{S}P employs a polar grid with resolution concentrated in one point. Thus, resolution is very high close to the center of the model (the site) and gets progressively lower towards the edge of the model.
- The grid of the model is "zooming", i.e. the scale of the grid is adjusted so it contains the entire domain described in the digital map.

The relation between domain size[9] and the grid size at the center of the model is illustrated in the table below. The radial grid size is enlarged by 6 per cent from one cell to the next.

Domain size	[km]	5	10	20	50	100
Grid size	[m]	1.3	2.7	5.3	13.3	26.6

In practice, a disk file containing the digital map should be prepared. The contents of a map file in Cartesian and polar coordinates, respectively, are given schematically in table 6 and 7. A sample map file — `WASPDALE.MAP` — is provided on the WAsP Data Diskette.

Line	Contents
1	Character string identifying the file: + ...
2	Fixed point # 1 in user and metric [m] coordinates: X_1^{user} Y_1^{user} X_1^{metric} Y_1^{metric}
3	Fixed point # 2 in user and metric [m] coordinates: X_2^{user} Y_2^{user} X_2^{metric} Y_2^{metric}
4	Scaling factor and offset for height scale (z). $z_{metric} = scaling\ factor \times (z_{user} + offset)$
5	Height of contour line and number of points in line
6–	X_1 Y_1 [... X_n Y_n] X_{n+1} Y_{n+1} ⋮ where [ ] embrace optional parameters and $n \geq 1$.
	The pattern from line 5 and onward is repeated as many times as there are contour lines in the map.

Table 6: Contents of a map file in Cartesian coordinates. The + in column one of the first line designates "Cartesian" and is mandatory. If the coordinates provided are metric and absolute, line 2–3 may be replaced by one line containing non-numeric input.

The most convenient way of obtaining the map coordinates is by digitizing the contour lines of a standard topographical map. The actual coordinates derived

[9]Domain size is defined here as the distance from the model center to the point farthest away from this in the map.

Line	Contents
1	Character string identifying the file: * ...
2	Fixed point in user and metric [m] coordinates: X_1^{user} Y_1^{user} X_1^{metric} Y_1^{metric}
3	Distance and angle in user and metric units: D^{user} θ^{user} D^{metric} $\theta^{absolute}$
4	Scaling factor and offset for height scale (z). $z_{metric} = scaling\ factor \times (z_{user} + offset)$
5	Height of contour line and number of points in line
6–	r_1 θ_1 [... r_n θ_n] r_{n+1} θ_{n+1} ⋮ where [ ] embrace optional parameters and $n \geq 1$.
	The pattern from line 5 and onward is repeated as many times as there are contour lines in the map.

Table 7: Contents of a map file in polar coordinates. The * in column one of the first line designates "polar" and is mandatory. The angles in line 3 are both given in degrees from N.

from the digitizer may be in any units as WA^SP is capable of transforming these into metric units on the basis of two fixed points. Most digitizers provide Cartesian coordinates. It its recommended to use standard map coordinate systems, like the Universal Transverse Mercator (UTM) provided on many topographic maps.

In case an electronic digitizer is not available you may have to obtain the coordinates manually. This can be attained using for example a protractor of the nautical plotter type. If this is not feasible or the terrain is relatively simple, a Gaussian hill may be specified as explained in the next section.

6.2 Invoking the flow model

Entering the digital map and initializing the BZ model is performed via the `OROGRAPHY` sub-menu:

```
Keywords:  MAPFILE HILL SITE PROFILE CLEAR DOS HELP RETURN
```

If the input is a disk file containing a digitized map, the `MAPFILE` option should be invoked. Given the file name (default extension `.MAP`) WA^{S}P transforms the contours to its internal format on the basis of the information given in the file.

Alternatively, WA^{S}P may generate the digital height contours of a simple Gaussian hill. The height, location, orientation and horizontal dimensions of the hill are specified by the user. This is obtained through the `HILL` option.

`MAPDATA` and `HILL` only enters the digital map to WA^{S}P. The `SITE` option centers the model grid on a specific point, adjusts the model radius according to the domain size and initializes the model. The site coordinates must be entered in metric units. Returning to the main display and updating the screen ($<cr>$) will execute the BZ model. The model derived wind speed changes and turning of the wind for each sector is shown in the main display. In addition, the number of curves and points specifying the terrain and the model grid radius are given. Changing the height of calculation in the main display (`HEIGHT`) and updating the screen will lead to model results for the new height. However, the vertical profile of terrain induced pertubations may also be explored by invoking the `PROFILE` option of the `OROGRAPHY` menu. This gives the speed and direction changes above the site for five standard heights (10, 25, 50, 100, 200 m a.g.l.) as well as for the height specified by the user.

The `CLEAR` option removes the map from the scenario (indicated in the main display). The map is still present in the memory of the computer, however, and may be reactivated by invoking the `SITE` option again.

7 Making a windatlas

The main purpose of WA^{S}P is twofold. Firstly, it incorporates routines to correct wind data measured at a specific point and transform these in to a data set describing the wind climate of a region — a socalled windatlas. Secondly, it utilizes such data sets to estimate the wind conditions at any particular site and height in the region, in principal by applying the same routines. The Danish Windatlas (Petersen *et al.*, 1981) contains a data set of this kind, obtained by methods similar to the ones employed by WA^{S}P. It also contains a user's guide describing how to utilize this data set to estimate the wind conditions; however, strictly speaking only applicable to Denmark.

WA^{S}P integrates the various models mentioned in the preceding chapters, and is thus capable of producing windatlas data based on surface wind observations as well as on geostrophic wind data; the latter derived from radiosonde observations or surface pressure analysis. The reason for estimating the wind climate at a specific point of interest by applying windatlas data for that region is discussed in Jensen *et al.* (1984).

Making a windatlas using WA^{S}P proceeds in the following steps:

1. The measured meteorological data, whether in the form of a time-series or a climatological table, are transferred to disk file and processed as described in section 3.

2. The description of the meteorological station may be entered directly from the keyboard and subsequently stored on disk file for further reference. The description comprises the anemometer height, the surface roughness conditions around the station, and possibly the presence of sheltering obstacles close to the station.

3. In case the measurements are thought to be influenced by orographic forcing, the information required by the complex terrain model should be provided as well (section 6).

4. Based on the information given in points 1–3, WA^{S}P calculates for each sector and wind speed class in the histogramme, the corresponding wind direction and wind speed far upstream of the anemometer. In this process the data are "cleaned" for the effects of nearby obstacles, roughness inhomogeneities, and perturbations due to terrain geometry.

5. Using the empirical relations between the wind over homogeneous terrain and the overlying large- or synoptic scale wind, the data are extrapolated to yield the geostrophic wind climate for the region. This is considered to be independent of the specific conditions at the surface. This process is referred to as "upward transformation" in the programme.

6. The inverse calculation is then performed ("downward transformation"), to obtain the wind climate at several standard heights and over various standard surface roughnesses.
7. Finally, these data are analysed in terms of the Weibull distribution function. The Weibull parameters obtained constitute the "windatlas" for the region in question and is the starting point for wind energy siting calculations.

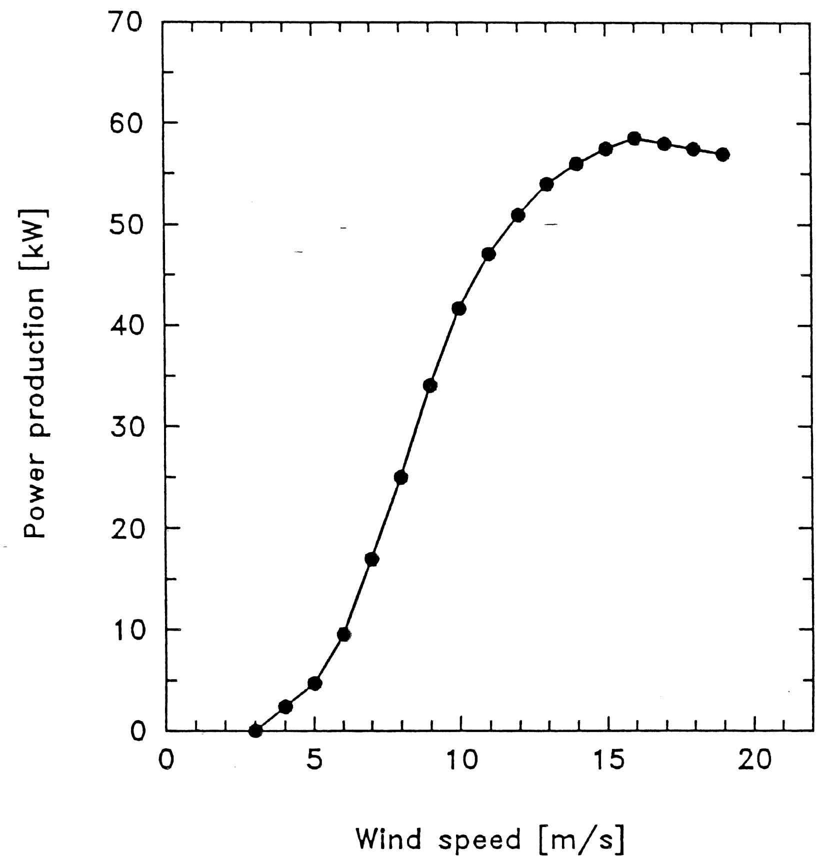
The windatlas calculation procedure outlined above in points 4–7 is performed by WA^{S}P upon invoking the `ATLAS` option of the main menu or the `DATA` sub-menu. The raw data set supplied is transformed into Weibull A and k parameters for 4 roughness classes, 5 standard heights and 12 azimuth sectors. The calculated windatlas thereafter replaces the "current" windatlas of WA^{S}P, as indicated in the main display. Hence, you may immediately proceed with siting calculations. Changing the site description, setting a new height, specifying a new obstacle list and moving the site in the terrain, WA^{S}P calculates and displays the wind climate for that particular site and height.

The `ARCHIVE` option lets you store the generated windatlas for future use, in which case the file is retrieved with the `LIBRARY` option.

8 Estimation of wind power

A question of primary interest in wind power applications is: "What power production can be expected from a given wind turbine at a given site ?". To answer this, it is necessary to know the power curve of the wind turbine as well as the probability density function of the wind speed at hub height. The product of these two functions gives the power density curve, the integral of which is the mean power production. This integral is evaluated by WA^{S}P in terms of the Weibull distribution parameters and approximating the power curve with a piecewise linear function.

The power curve of a wind turbine gives the energy it can produce as a function of wind speed. A sample power curve for a 55 kW rated wind turbine is shown in fig. 15. Like most actual power curves it is rather smooth and very well described by a piecewise linear function.




```
55 kW WECS
24.0
  1.0 1000.0
  3.0    0.0
  4.0    2.4
  5.0    4.7
  6.0    9.5
  7.0   17.0
  8.0   25.0
  9.0   34.0
 10.0   41.6
 11.0   47.1
 12.0   50.9
 13.0   54.0
 14.0   56.0
 15.0   57.5
 16.0   58.5
 17.0   58.0
 18.0   57.5
 19.0   57.0
```

Figure 15: Power curve of a 55 kW wind turbine. The power curve is plotted as a piecewise linear curve with nodes for every 1 ms^{-1}. The corresponding input file to WA^{S}P is shown on the right.

The probability density function or distribution function gives the frequence of occurrence of a given wind speed. Estimating the relevant probability density function or Weibull distribution is the subject of the preceding chapters.

8.1 Determining mean power production

Before invoking the `WECS` option of the main displays, a disk file containing the power curve data of the wind turbine in question should be prepared. The file corresponding to the sample power curve mentioned above is shown in fig. 15 and contains the following information: *Line 1* is a character string identifying the contents of the file. *Line 2* states the actual or projected hub height of the wind turbine. *Line 3* gives two scaling factors for wind speed and power output, respectively. These scaling factors are simply the conversion factors from the units of speed and power used in the file, to $[ms^{-1}]$ and $[W]$, respectively. From *Line 4* and onward, corresponding values of wind speed and power output are listed. The power curve may be described by a maximum of 100 points.

Having prepared the power curve file and established the wind statistics, the `WECS` option may be invoked. WA^{S}P will then ask for the name of the power curve file — assuming `.POW` as file extension if not otherwise told — and read this. The yearly, mean power production of the wind turbine is then calculated and shown in the main display. Please observe that *the current height of WA^{S}P is set to the hub-height* as read from the file. However, by using the `HEIGHT` option you may even estimate the power production for various hub-heights. Note also that the units given may vary according to the actual size of the power production. Once the `WECS` option is invoked, the power production of the wind turbine is recalculated each time the main display is refreshed.

Furthermore, the main display gives the total energy available in the wind, i.e. the average kinetic energy flux per unit area. This quantity may be useful in a preliminary evaluation of the wind power potential at several different sites.

A more detailed treatment of wind power estimation in general is given in Petersen *et al.* (1981) and Jensen *et al.* (1984).

The sample power curve shown in fig. 15 is provided on the WA^{S}P Data Diskette as `WECS55.POW`.

9 Using WA^{S}P - an example

The practical application of WA^{S}P can be illustrated by the following brief example. The complete data set of the example is provided on the WA^{S}P Data Diskette and many of the figures in this User's Guide were produced using the sample data.

The Waspdale community wishes to erect a wind turbine on Beeverly Hill. An artists conception of the final result is shown in fig. 16. Waspdale is situated in a moderately complex terrain. In order to estimate the expected power production of the turbine, wind data from the local airport has to be extrapolated to the projected turbine site.

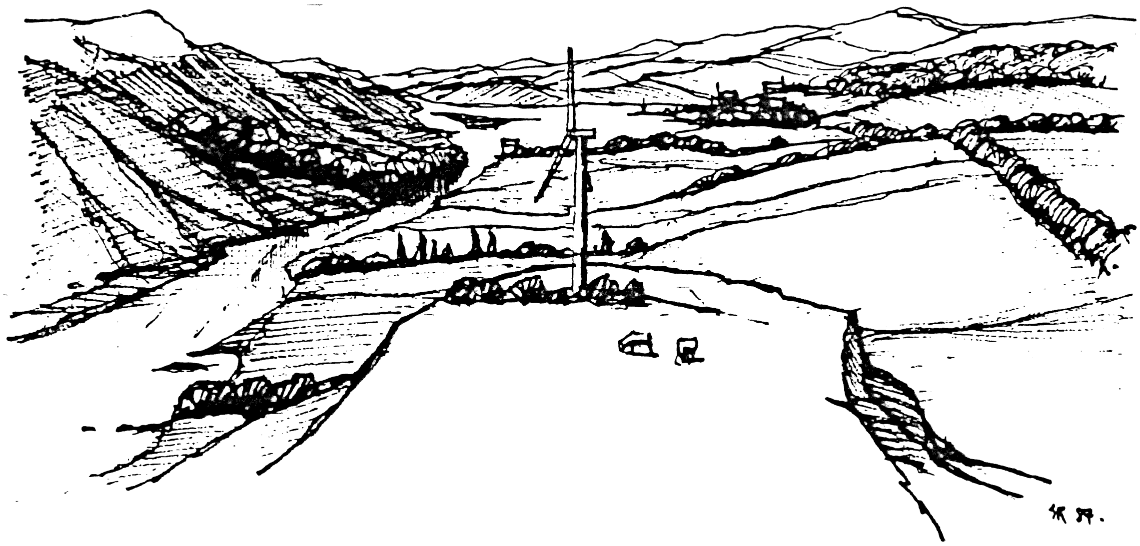
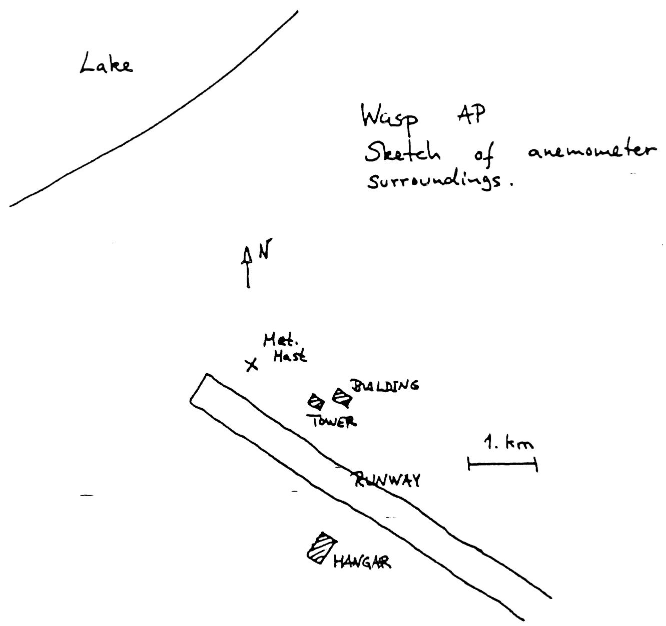


Figure 16: Waspdale with the projected wind turbine (drawing by S. Rasmussen).

9.1 From raw data to windatlas

A three year time-series of three-hourly observations of wind speed and direction is obtained from the airport, 7 km north of the WECS site. The data are analysed using the `RAWDATA` option of WA^{S}P, and the resulting histogramme is stored on disk file for future reference. A summary of the observations is given in fig. 3 and fig. 4 shows the corresponding histogramme file.

The anemometer height and information on the surroundings close to the meteorological mast are necessary to correct the raw data. Figure 17 shows a sketch map of the airport area. Three obstacles near the anemometer are expected to influence the measured wind speed. In addition, the anemometer is mounted beside a wind vane, with the result that winds in the 120 deg. sector are reduced by ≈5 per cent.



OBSTACLE DESCRIPTION

L	α_1	R_1	α_2	R_2	h	d	type
1	118	105	125	105	12	20	Tower
2	109	135	116	130	6	25	Build.
3	157	290	160	270	8	38	Hangar.

Remarks.
Winds from 120° sector are sheltered by windvane (speed reduced 5 %).

Figure 17: Sketch map of Wasp Airport showing major obstacles in the vicinity of the meteorological mast.

The surface roughness conditions around the mast are classified using a topographic map and information supplied by the airport meteorologist. Furthermore, the terrain characteristics necessitate that we take the modification of the wind due to the orography into account. The height contour lines are extracted from the topographical map and a file containing the digital map is prepared. In this case the coordinates are absolute, given in metric units, and fixed points need not be specified (cf. `WASPDALE.MAP`). Figure 18 shows a plot of the map. The contour interval is 25 m in general, but some 10-m contours have been added close to the projected WECS site, in order to resolve the geometry of the hill.

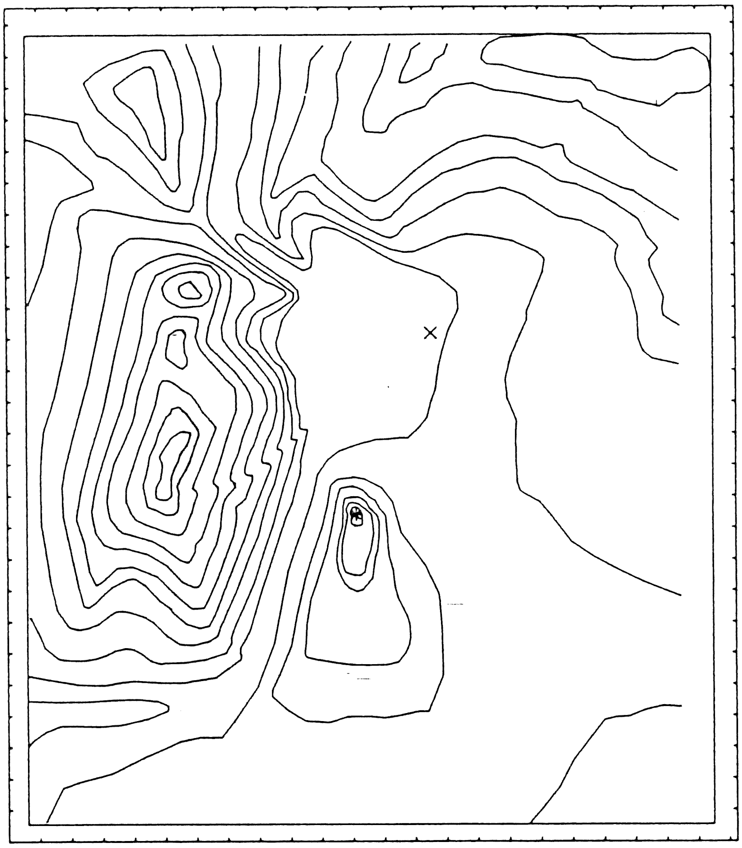


Figure 18: Plot of the contour map of Waspdale. The cross indicates the airport anemometer and the asterisk the WECS site. The terrain is described by 31 contour lines or about 1200 points.

The site description and obstacles are entered to WA^{S}P from the keyboard, whereas the digital map is read from file. The site is set to the meteorological station (29662,39127). Invoking the ATLAS option results in the calculation of a windatlas for the area.

9.2 Siting a wind turbine

The windatlas forms the basis for estimating the wind climate at any location in the area. Since the current data set applies to the projected wind turbine site, estimating the wind climate at this site may be performed directly. The roughness description of the WECS site is entered, the obstacle list is cleared and the center of the BZ model is moved to the new site (27139,33371). Finally, the power curve of the wind turbine is read. This sets the height of calculation to the projected hub height (24 m), leading to the desired result (fig. 19).

```
Wasp Airport 1983-85.
------------------------------------------------------------------------------
WECS site - Beeverly Hill Height  24.0 m a.g.l.           A     k       %
------------------------------------------------------------------------------
  0: .05<1000 .10<3000 .00<7500 .10<                 :   5.5  2.11    2.4
 30: .05<3000 .30<                                   :   6.0  2.05    4.5
 60: .05<                                            :   5.8  1.92    6.6
 90: .05<                                            :   5.5  2.54    7.6
120: .05<                                            :   5.6  2.42    5.6
150: .05<                                            :   5.5  2.29    4.6
180: .05<                                            :   6.9  2.21    7.1
210: .05<                                            :   7.6  1.54    9.0
240: .05<                                            :   9.6  2.55   14.3
270: .05<2000 .01<                                   :   7.8  2.43   16.5
300: .05<2000 .01<                                   :   7.4  2.43   14.7
330: .05<2500 .01<                                   :   5.6  2.03    7.0
------------------------------------------------------------------------------
M=  6.3 m/s    E=  296. W/m**2    P= 144.9 MWh/y   A,k=  7.1  1.97

  RDS HEIGHT TEXT DATA ATLAS OBSTACLE OROGRAPHY WECS FREQUENCY
  DISPLAY RETURN DUMP RELOAD DOS HELP STOP
```

```
WECS site - Beeverly Hill Height:  24.0 m. a.g.l.
------------------------------------------------------------------------------
sect    rch      input       obstacle     orography          A     k       %
------------------------------------------------------------------------------
  0:     3    0.0%    0deg    0.0%    9.1%    3deg  :   5.5  2.11    2.4
 30:     1    0.0%    0deg    0.0%   12.4%    3deg  :   6.0  2.05    4.5
 60:     0    0.0%    0deg    0.0%   16.9%    0deg  :   5.8  1.92    6.6
 90:     0    0.0%    0deg    0.0%   15.2%   -2deg  :   5.5  2.54    7.6
120:     0    0.0%    0deg    0.0%   10.3%   -3deg  :   5.6  2.42    5.6
150:     0    0.0%    0deg    0.0%    7.0%   -1deg  :   5.5  2.29    4.6
180:     0    0.0%    0deg    0.0%    8.9%    3deg  :   6.9  2.21    7.1
210:     0    0.0%    0deg    0.0%   13.9%    3deg  :   7.6  1.54    9.0
240:     0    0.0%    0deg    0.0%   16.9%    0deg  :   9.6  2.55   14.3
270:     1    0.0%    0deg    0.0%   16.9%   -3deg  :   7.8  2.43   16.5
300:     1    0.0%    0deg    0.0%   11.6%   -3deg  :   7.4  2.43   14.7
330:     1    0.0%    0deg    0.0%    7.7%   -1deg  :   5.6  2.03    7.0
------------------------------------------------------------------------------
M=  6.3 m/s    E=  296. W/m**2    P= 144.9 MWh/y   A,k=  7.1  1.97

Orography: 1167 points in 31 contour lines.  Model radius : 27.558 km
Obstacles: 0 Obstacles specified.

  RDS HEIGHT TEXT DATA ATLAS OBSTACLE OROGRAPHY WECS FREQUENCY
  DISPLAY RETURN DUMP RELOAD DOS HELP STOP
```

Figure 19: Main displays of WA^SP for the WECS site. The mean power output of the projected wind turbine (P) is calculated using the actual power curve for the turbine in question, in this case a 55 *kW* WECS.

10 References

Jackson, P.S. and J.C.R. Hunt (1975). Turbulent wind flow over a low hill. Quart. J. Roy. Met. Soc., **101**, 929–955.

Jensen, N.O, E.L. Petersen and I. Troen (1984). Extrapolation of mean wind statistics with special regard to wind energy applications. World Meteorological Organization, WCP–86, 85 pp.

Lettau, H. (1969). Note on aerodynamic roughness–parameter estimation on the basis of roughness–element distribution. J. Appl. Met., **8**, 828–832.

Perera, M.D. (1981). Shelter behind two-dimensional solid and porous fences. J. Wind Engin. and Industrial Aerodyn., **8**, 93–104.

Petersen, E.L., I. Troen, S. Frandsen and K. Hedegaard (1981). Windatlas for Denmark. A rational method for wind energy siting. Risø–R–428, 229 pp.

Petersen, E.L and I. Troen (1986). Estimation of wind resources. In: Wind Energy in Denmark. Research and technological development. Ed. Fl. Øster. Published by the Danish Ministry of Energy, 29–36.

Petersen, E.L. and I. Troen (1986). The European Wind Atlas. Proceedings of the European Wind Energy Association Conference and Exhibition, Rome, October 7–9, 1986, 191–200.

Taylor, P.A. and H. Teunissen (1983). Progress report to the International Energy Agency's Programme of Research and Development on Wind Energy Conversion Systems, Task VI: Study of local wind flow at potential WECS hill sites. Atmospheric Environment Service, Canada.

Taylor, P.A., J.L. Walmsley and J.R. Salmon (1983). A simple model of neutrally stratified boundary–layer flow over real terrain incorporating wavenumber–dependent scaling. Boundary–Layer Meteorol., **26**, 169–189.

Troen, I. (1987). BZ: A high resolution spectral model for flow in complex terrain. To be published.

A The keywords of WA^{S}P

Keywords: RDS HEIGHT TEXT DATA ATLAS OBSTACLE OROGRAPHY WECS FREQUENCY DISPLAY RETURN DUMP RELOAD DOS HELP STOP

RDS — Input of site description, i.e. the surface roughness conditions around the site. Local wind speed corrections and wind direction correction angles for each sector may be entered too.

HEIGHT — Sets a new height for which calculations are performed.

TEXT — Input of a character string that identifies the site description given in the display.

DATA — The WA^{S}P input and output routines to handle measured meteorological data, general climatological data - whether upper-air or at ground stations - or processed data in the form of windatlas tables, are collected in this sub-menu. Section A.1 describes the DATA keywords.

ATLAS — Calculation of windatlas data. The input is a table giving the frequency of occurence of wind speed versus direction. The table is read from disk with the TABLE option or is present through execution of the RAWDATA option (app. A.1).

OBSTACLE — Input and editing of the obstacle list for a specific site is taken care of by this sub-menu. Section A.2 describes the OBSTACLE keywords.

OROGRAPHY — Input of a digitized map of the area or an idealized orography and initialization of the complex terrain model. The effects of terrain on the wind profile at the site can also be investigated. The OROGRAPHY keywords are described in section A.3.

WECS — Input of a WECS power curve. The yearly power production of the wind turbine in question is shown in the main display and recalculated as the display is updated.

FREQUENCY — Calculates the probability that the wind speed lies in certain user-specified intervals of wind speed and direction.

DISPLAY — Switches between the two main displays of WA^{S}P. The site description is shown in the first display whereas the second lists the effects of obstacles and the terrain in the different sectors. The number of roughness changes in each sector, the number of obstacles specified, and the number of curves and points defining the terrain is also given in this display. Both displays give the Weibull parameters and frequency of occurence for each sector.

RETURN — Invokes the different models of WA^{S}P and updates the screen with the new results. Identical to $<cr>$.

DUMP — The roughness description and user-specified correction factors can be stored on disk by executing the DUMP option.

RELOAD — Reloading an existing site description from disk.

DOS Entering and returning from the Disk Operating System without terminating WAsP. This allows the user to execute DOS commands while having a WAsP session, e.g. checking a directory on disk or editing a file to be input later to WAsP.

HELP WAsP offers a brief description of the keywords and their usage.

STOP Stops the execution of WAsP. ***Data and results not stored on disk files will be lost.***

A.1 The DATA keywords

Keywords: **RAWDATA LIBRARY TABLE ATLAS ARCHIVE DOS HELP RETURN**

RAWDATA Input of raw (measured) data in the form of a time-series of wind speed and direction. The input is an ASCII or binary file with one observation per record, and any format of the variables may be treated. Lower and upper limits for speed and direction can be specified, and linear conversions can be applied. **RAWDATA** displays a summary table when the time-series has been processed. This table can be stored on a disk file and retrieved at a later stage with the **TABLE** option.

LIBRARY Input of windatlas data. These may derive from The Danish Windatlas, The European Windatlas or they may be supplied by the user. The results of a WAsP session can also be stored as windatlas data. The Danish Windatlas is supplied with WAsP now, the European Windatlas will be available in the near future.

TABLE Input and output of general climatological data, i.e. statistical tables giving the frequency of occurence of wind speed versus direction. This table may also be the output produced by **RAWDATA**.

ATLAS Calculation of windatlas data. The input is a table giving the frequency of occurence of wind speed versus direction and a complete description of the site. The table is read from disk with the **TABLE** option or is present through execution of the **RAWDATA** option. The site description is entered via the keyboard or retrieved from disk files.

ARCHIVE Saving the results of a WAsP session as windatlas data.

DOS Entering and returning from the Disk Operating System without terminating WAsP. This allows the user to execute DOS commands while having a WAsP session, e.g. checking a directory on disk or editing a file to be input later to WAsP.

HELP As in the main display.

RETURN Returning to the main display of WAsP. Identical to <*cr*>.

equivalent to

A.2 The OBSTACLE keywords

Keywords: `INPUT EDIT MOVE CLEAR DUMP RELOAD DOS HELP RETURN`

`INPUT` Input of obstacles from keyboard. Each obstacle is specified by its position (two azimuth angles and two distances) and a width, a height and a porosity. A maximum of 50 obstacles can be specified.

`EDIT` Editing in or extending the obstacle list.

`MOVE` Moving the site relative to the obstacles specified.

`CLEAR` Clearing the obstacle list before performing calculations for a new site.

`DUMP` Storing the obstacle list entered via the keyboard on a disk file.

`RELOAD` Reloading an existing obstacle list from disk file.

`DOS` As in the main display.

`HELP` As in the main display.

`RETURN` Returning to the main display of WA^{S}P. Identical to <*cr*>.

Equivalent

A.3 The OROGRAPHY keywords

Keywords: `MAPDATA HILL SITE PROFILE CLEAR DOS HELP RETURN`

`MAPDATA` Input of a digitized map from file. The map consists of strings of coordinate pairs (x, y) or (r, θ), each string defining a height contour line. The coordinates and heights may be supplied in any units, as WA^{S}P is capable of transforming these into metric units on the basis of two coordinated points.

`HILL` If a digitized map of the area is not readily available or the terrain is relatively simple, WA^{S}P can generate the contour lines of a simple Gaussian hill. The height, location, orientation and horizontal dimensions of the hill are specified by the user.

`SITE` Setting the site coordinates on the map. The BZ model centers the polar grid at this point and adjusts the outer radius to contain the entire map.

`PROFILE` Gives the change in wind speed and turning of the wind - imposed by the terrain - for five standard heights (10, 25, 50, 100 and 200 m a.g.l.) as well as for the height specified by the user.

`CLEAR` Clearing the map from the scenario. However, the digitized map is still present in the memory of the computer and the terrain model may be reactivated by executing the `SITE` option.

`DOS` As in the main display.

`HELP` As in the main display.

`RETURN` Returning to the main display of WA^{S}P. Identical to <*cr*>.

Equivalent

B The files of WA^{S}P

WA^{S}P operates with seven different categories of disk files that the user should also be familiar with, since this will save a lot of typing in of data. The files are used to store information that is required by WA^{S}P during execution. Some of the files can be generated by dumping the information typed in during a session, while others must be prepared beforehand. To avoid confusion and enhance systematics WA^{S}P assumes a default file extension with each of the seven types. However, the user may specify the name completely and thereby override the default choice[10]. A short description of these files is given below, with reference to the page in the manual where they are introduced.

`.DAT` Data file. ASCII or binary file containing meteorological time-series data. Must be prepared before running WA^{S}P. A separate programme – `CONVERT.EXE` – on the Data Diskette converts ASCII files to binary files. Binary files are processed much faster and usually require less disk space. See section 3.1 on page 12.

`.TAB` Table file. ASCII file containing a table or histogram. This file may be prepared beforehand from an existing climatological table or may be generated by processing a time-series. See section 3.2 on page 14.

`.RDS` Roughness description file. ASCII file containing a site description. Generated by dumping the site description. See section 4.2 on page 24.

`.MAP` Map file. ASCII file containing digitized height contour lines. Must be prepared before invoking the `MAPFILE` option. See section 6 on page 35.

`.OBS` Obstacle description file. ASCII file containing the obstacle description of a given site. The information is entered from the keyboard during a WA^{S}P session. See section 5 on page 30.

`.LIB` Windatlas file. ASCII file containing windatlas data for a given site. The result of running the windatlas model may be stored in the users "library" of windatlas data. Generated by invoking the `ARCHIVE` option. See section 3.3 on page 16.

`.POW` Power curve file. ASCII file containing the power curve of a certain wind turbine. Must be prepared beforehand using a text editor. See section 8 on page 41.

Note that these files are *not* stored automatically. You must explicitely invoke the relevant `DUMP` options to store the `.TAB`, `.RDS`, `.OBS` and `.LIB` files. Leaving WA^{S}P without saving the results means that you will have to type the information or run the models again.

[10]Filenames without an extension must be ended by a punctuation mark.

C Sample forms

The following two pages contain sample forms that may be useful when describing a site. These are:

1. Obstacle Description Form
2. Roughness Classification Form

The very last page of this manual is a Software Report Form. Use this form to report software bugs, documentation errors, or suggested enhancements to WA^{S}P. The form should be mailed to the distributor of WA^{S}P.

OBSTACLE DESCRIPTION FORM

Station: ______________________________ **Date:** ______________

byt om

#	α_1	R_1	α_2	R_2	d	h	type

α is given in degrees from north and R in metres.

Additional information:

ROUGHNESS CLASSIFICATION FORM

Station: ______________________________ Date: ______________

Sector		z_{01}	X_1	z_{02}	X_2	z_{03}	remarks
1	0						
2	30						
3	60						
4	90						
5	120						
6	150						
7	180						
8	210						
9	240						
10	270						
11	300						
12	330						

z_0 and X are given in metres.

Additional information:

Name: ____
Street: ____
City: ______________________ Zip code: ____________
State/country: ______________________________________

WA^S^P serial #: ________________ Release: ____________
Computer make/model: _______________________________
DOS version: _______________________________________

Description of error condition:

Suggestions for WA^S^P updates: